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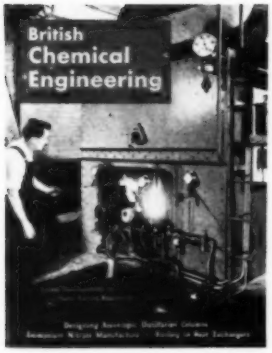

Oil-fired steam plant employing a Fraser & Fraser water-tube boiler equipped with flame-failure devices at the Armstrong Cork Company's processing plant at Kingsbury.

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BRITISH CERAMIC ENGINEERING

DIGEST OF INDUSTRIAL AND TECHNICAL DEVELOPMENTS

The Trend in Manufacturing Investment

APTEST comments on the latest investment cuts were made in advance of the events. "If a manufacturing country is to retain its position in world markets frequent innovation is necessary in terms both of products and of processes. If capital equipment is being extensively added to and not merely replaced technical change of this kind is facilitated". These observations by the Economic Commission for Europe are quoted with approval by T. Barna in the "F.B.I. Review" (Oct., 1957) in the course of discussing whether enough is being invested in manufacturing industry. Dr. Barna points out that in terms of capital formation per head of population Britain, Western Germany and France were close together up to 1953 but since then Germany has overtaken us and France has fallen behind. Other comparisons with Western Germany, United States and in more guarded fashion the Soviet Union, in terms of the percentage of the national product are also disturbing in what they reveal. A careful analysis of the economic, including demographic, factors leads to this conclusion. There must be continuous expansion in national output, consumption and investment at a rate requiring an annual 5% to 6% growth in the volume of manufacturing investment. If this happens by 1967 manufacturing investment will rise in terms of today's prices to £1,550 million. Applying these criteria and returning strictly to our own muttons we find a more encouraging picture than that shown by industry as a whole. Capital investment in chemical plant rose from £33 million in 1948 to over £100 million in 1956, according to Mr. G. N. Hodson, chairman of the British Chemical Plant Manufacturers' Association. Future plans reported show continued expansion and in petroleum chemicals alone it is expected that the total capital investment of £55 million in 1955 will have been doubled by the end of 1958.

Can You Use Square Bubbles?

OF course the question of immediate utility should never enter into the assessment of research. Yet it is impossible to prevent this intriguing question from coming to mind on learning that square bubbles have been produced. Peter Senio, a metallurgist at the Knolls Atomic Power laboratory, recently disclosed that brilliantly coloured microscopic bubbles in square and rectangular forms appear in lithium floride crystals after they have been irradiated with neutrons in a reactor, then heated above 600°C. Formation of helium and tritium in the irradiated salt is thought to be responsible for the bubbles which are formed in the following way. Small pieces of clear lithium chloride are irradiated with neutrons in a reactor and are found to turn black. They are then heated and at about 450°C become clear. After they have been maintained at about 700°C for several hours they look frosted to the naked eye. Under the microscope the crystals then reveal colour squares formed inside and most frequently along natural faults of the crystals. The overall appearance of groups of the bright bubbles is said to be somewhat similar to squares used in stained glass windows arranged in cubist design. Above 700°C the bubbles begin to round and as the melting point is approached (842°C) they grow and combine to form new shapes. These are described with American lyricism as resembling "sausages, doughnuts, boomerangs and many other familiar objects". Ultimately, tiring of the game, the bubbles staidly form spheres.

Who Can Save Fuel?

AT the silver jubilee convention of the Coal Utilisation Council several of the eminent figures connected with the fuel industries emphasised the need to use our coal more economically. In this connection it is interesting to recall the paper exercise carried out during last year by the National Industrial Fuel Efficiency Service. To examine whether their heat and power surveys were well distributed over the whole of industry the engineers made a comparison between the distribution of the surveys and the distribution of coal consumers represented by the various industrial groups. Generally the two sets of figures corresponded remarkably closely except for the ceramics group. This was a matter for concern because the fuel savings that were found to be possible averaged 18.4% overall but reached 29.3% for ceramics. In none of these surveys was the saving to be secured less than 10%. In chemicals 14.2% of the fuel could be saved. A second test was made of whether there was equitable spread of the work of N.I.F.E.S. This was based on comparing the relative numbers of consumers classified according to tonnage of coal used and the relative number of surveys within the same tonnage categories. There was excellent correlation between the two sets of figures. Thus, although the sample of British industry covered by this work was limited the results are likely to be representative of the whole of industry. In absolute figures the work during 1956/7 covered the consumption of over 1,200,000 tons of coal and pointed the way to savings exceeding 220,000 tons per annum. If this is a fair sample there are savings of between 7 and 10 million tons per annum to be achieved —for the most part by improved operation of existing plant, for the rest with relatively low capital expenditure.

Time For Decision on Coal Policies

Looking beyond the present fuel famine, we see the prospect of an excess of coal within a few years—particularly of small coals with a high volatile content. For in the long run the industrial energy demand will be carried by atomic power. In his Dalton lecture to the Royal Institute of Chemistry, Dr. J. Bronowski recently set out some of the steps towards using coal as a source of special fuels and ultimately of fluid fuels and chemicals. In the form of coke, coal has long been an important chemical. Now fluid beds will be used to make a coke

powder or char as the basis of a new briquetted smokeless fuel. As a second step the char may be turned into gas and some of this gas may then be used for synthesis of gas-oil and similar products. This will form both a rational use for the otherwise surplus coal and yield large quantities of chemicals which will apparently be needed judging by extrapolation of trends. Beyond the next twenty years, hydrogenation processes are seen as a likely development. The tone of the conclusions suggests that this view is not yet accepted by the authorities responsible for allotting research funds. Although his remarks carry the weight of a key position—director of the N.C.B. Coal Research Establishment—Dr. Bronowski twice stated that these were personal views. It is true that the (organisationally separate) Fuel Research Board has recommended an increase in the programme on synthesis from carbon monoxide and hydrogen in the new Research Station at Stevenage and other bodies working on fuel research report increases in programmes from time to time. Yet much bigger decisions are needed concerning the prospects of the coal industry, its future output and the use to be made of its main product.

Simplifying Liquid Hydrogen Storage

A STRIKING example of an advance in pure physics having an immediate impact on engineering practice has been reported from the U.S. National Bureau of Standards. An unusually effective catalyst for converting ortho- to para-hydrogen, hydrous ferric oxide, has been found to simplify liquid hydrogen storage. This is because the orthomolecules are unstable at low temperatures and change into paramolecules, liberating heat energy in the process and causing wasteful evaporation. Before the development of conversion catalysts, the problem could be met only by the use of special refrigeration equipment to remove the heat generated during the relatively long time needed for the orthohydrogen to change to parahydrogen. The development of effective catalysts has made possible the reliable, continuous production of liquid hydrogen having a high para content. The necessity for cumbersome and expensive refrigeration equipment to absorb the heat of conversion at the storage site is eliminated since liquid parahydrogen is transferred to storage directly from the liquefier where the catalysis takes place. The scale of the change required can be assessed from these figures. At room temperature, so-called "normal" hydrogen at equilibrium contains 75% orthohydrogen and 25% parahydrogen. At the boiling temperature (−423°F), the equilibrium ratio shifts to 0.2% orthohydrogen and 99.8% parahydrogen. The slow natural ortho-to-para conversion, which continues until eventually 99.8% of the liquid is parahydrogen, is caused by a process known as "self catalysis". This means that if two orthohydrogen molecules approach one another closely enough their magnetic fields interact (orthohydrogen molecules being magnetic) and unbalance the molecules so that a reorientation of spins takes place. However, the frequency of these events is such that it takes about a month for normal 25% para liquid to convert to 90% para. The heat energy released during this month of self conversion is enough to boil away 64% of the original liquid.

Economic Answers to Corrosion

IT is natural enough that each manufacturer of corrosion preventives should trumpet his own wares, but it is the reciprocal of this information that is rather more valuable to the engineer. For a given problem, he asks, what is the economic answer. This involves knowing the drawbacks and limitations of each product or method considered. Short-sighted manufacturers may show some reserve about these aspects. The combination of a Corrosion Exhibition and Convention can therefore be particularly valuable. Papers presented at the recent Convention in London included surveys of the selection of corrosion-resistant metals by the head of corrosion research at I.C.I. Metals Division and on corrosion in the atomic energy industry by workers at Risley. To open the programme was a paper by Dr. Footner of Shell Petroleum reviewing the protection of plant and equipment in the petroleum and chemical industries.

Fast Reactions at High Temperatures

REACTIONS at high temperatures present many points of both theoretical and practical importance. A survey of the factors operating in reactions at temperatures up to about 5000°C has recently been published by G. Porter.* Above this temperature molecular species disappear and matter consists almost wholly of atoms and ions. Dr. Porter lists the main problems of high temperature chemistry, that is below the limiting temperature, as being the following. Firstly there are the practical problems of producing high temperatures by chemical means. Secondly, we have to discover the nature of the substances that are stable at high temperatures and the equilibrium relations between them. Finally, we must study the rates of reactions at high temperatures, since they may determine the rates of flame propagation and similar phenomena. Main current reason for interest in this field is the attempt to achieve higher engine efficiencies in accordance with the second law of thermodynamics by using higher working temperatures, particularly for the newer jet and rocket engines. In the study of high temperature kinetics the outstanding experimental difficulty is to raise the temperature quickly enough to make significant rate measurements possible. If this can be done measurements can be made by electronic techniques even if the time of reaction is only a few microseconds. Two main methods are used for raising gas temperatures independently of the container. These are rapid adiabatic compression particularly by shock waves and irradiation usually by a short flash of visible or ultra-violet light.

* Porter, G. *Endeavour*, 1957, **16**, No. 64, 224.

More Data to Help Separate Fission Products

AS part of the studies of separation of fission products fresh data have been published by C. J. Anderson and M. Kibrick of the Vitro laboratories (U.S.A.) on the solubility of strontium sulphate in water and in nitric acid over the range 0° to 350°C. In the temperature range 0°—100°C which received special attention the attractiveness and feasibility of using a strontium sulphate precipitation process for the decontamination of acid wastes was found to depend upon the acid concentration of the waste and the degree of decontamination. Decontamination is a function of the original as well as the final concentration of strontium in the waste solutions. Dr. Anderson concluded that the decontamination of most acid wastes (assuming an initial concentration of about 1g of strontium/litre waste) would not be very high if the process depended solely upon the precipitation of strontium sulphate without a large excess of sulphate or an effective coprecipitating agent. An over-all evaluation of the data

indicated that acidities of less than 2.5M and greater than 7.0M will probably prove to be the most promising for a sulphate precipitation process in this temperature range. Apparently it is planned to study further the effect of coprecipitating agents on strontium removal at 250°C to estimate the degree of decontamination which might be attainable using a coprecipitation process. In addition an investigation of minerals as inorganic exchangers for caesium and strontium will be continued with the initial effort on batch tests at higher temperatures and in more concentrated acid solutions.

First, Build It Safe

SAFETY should be built in to plant at the design stage. This was the essence of the advice reiterated by Sir George Barnett, H.M. Chief Inspector of Factories, in his opening address to the S.C.I. Conference on "Safety in Chemical Industry". His department had been preaching this message for many years and it seemed that in the chemical industry they had achieved some response. While the average accident rate for industry was 1.73 per 100,000 manhours worked, that for the chemical industry was 1.43. Sir George also spoke of the importance of educating workers in dealing with chemical dangers and of attention to the siting of plant to minimise the consequences of any failures. The next useful stage in locating danger points may well be to analyse the figures by types of process in greater detail than at present and carry out mathematical-statistical analyses on them. The Annual Report of the Factory Inspectorate already includes a considerable amount of breakdown of accident figures by industry and by cause. Yet there may be advantage in going further. The quoted figure of 1.43 includes a rate of 3.35 for the coal tar industry group and there may be other striking figures in other sections of the industry.

Tackling Small Fires

THERE is no single best method of extinguishing small fires of flammable liquids. This is the conclusion to be drawn from results of a set of tests by the National Bureau of Standards using a set of five fire fighting reagents, discharged in a statistically designed group of tests by 15 extinguishers on 10 different types of fires. Heptane was used as the flammable liquid. The reagents were carbon tetrachloride and chlorobromomethane, carbon dioxide, dry sodium bicarbonate and foam. The tests revealed that fire configuration greatly influences the effectiveness of a particular extinguisher. Confining surfaces provide favourable conditions for efficient extinguisher action as the agent accumulates to a concentration necessary for putting out the fire. Methods of attack yielding optimum results vary with the fire model and particularly with the extinguisher. Generally, carbon tetrachloride is best employed by spraying on a hot surface to secure maximum vaporisation, and in such a manner as to cover the area with the decomposition products. Dry chemical extinguishers are most effective when operated to cover the whole flaming area at once. Carbon dioxide types seem to work best when the agent is discharged in a sweeping motion near the fuel surface. Foam is effective only if it can be made to flow directly on to the burning-liquid surface. A high rate of discharge in any particular type of extinguisher enhanced the effectiveness of the performance. Extinguishers of the type of the 1-qt. chlorobromomethane, 10-lb. carbon dioxide and 4-lb. dry chemical devices used in the tests rank very closely in usefulness on the test fires, and generally would be superior to the other types of extinguishers of the N.B.S. programme on flammable liquid fires of limited extent.

Break up the plant . . . or employ chemical engineers?

At the Annual Dinner of the Royal Institute of Chemistry (London Section), Prof. Blackett explained how he had been won over to appreciating the special role of chemical engineers. A research chemist—according to this apocryphal story—discovered a product of highly desirable properties. The management decided to go ahead with production and asked the chemist to prepare his apparatus and process for taking over by the engineers. He duly set up his glassware, with stirrers, tap funnel, reflux condensers and the rest as though for a normal preparation. The mechanical engineers came and measured up, then scaled up to the output required and constructed a plant in stainless steel. The chemist specified the reaction conditions, the engineers started up the heaters, the stirrers—then passed in the reactants. An hour later they came racing over to the research lab with an alarm call for the chemist standing by his beloved glassware. "The whole mass has set solid", they said, "What do you do now?" The chemist was puzzled by their treating this as a difficulty. "That is the normal course of the reaction. At this stage I smash the flask and remove the solid".

Use a Computer to Design Your Fractionating Column

IT is obvious in general terms that a computer would be useful for design of many items of plant. Specific examples, however, are still rather rare and it is useful to have available in a recent article a programme for computing-control of a fractionating column (*Control Engineering*, 1957, 4, No. 9, 144). In this, Howard L. Engel sets out the equations for the fractionation process which when solved repeatedly yield an appropriate feed tray, an economical reflux rate, and the amount of heat input for a column top-product of specified composition. Dr. Engel then describes the programme of a digital computer designed to carry out the calculations and to indicate the results on a display board. Initialiy, the system will have a human operator reading the information on the board and manually adjusting process conditions. But operating experience is expected to result in a closed loop incorporating the computer, the service being shared with several fractionators. This is because disturbances to conditions develop slowly so that—for control purposes—calculations are needed only infrequently and a large amount of computer time would be wasted if it were restricted to controlling one binary fractionating column.

Fluidised Beds of Two Particle Sizes

IN a packed bed consisting of two particle sizes the transition from a fixed bed to a fluidised bed occurs over a range of flow rates in contrast to the behaviour of single particle sizes where this transition takes place completely at a well defined flow rate. This was one of the

findings of H. M. Katz at the Argonne National Laboratory in studies of these systems in a 2 in. diameter column. As the difference between the particle sizes becomes bigger the transition range becomes wider but it is always less than the range between the minimum fluidising velocities of the two particle sizes which are present. In the range of flow rates in this transition region the bed consists of two sections with a well defined interface. The lower portion of the bed is fixed and contains a higher percentage of coarse particles than the overall bed composition while the upper portion of the bed is fluidised and contains a lower percentage of coarse particles than the overall bed composition. Dr. Katz also observed that both static electricity and absorbed surface moisture are important variables affecting particle size distribution. The presence of either of these effects results in segregation of coarse particles at the bottom of a completely fluidised bed. Increase of flow rate under these conditions decreases the amount of segregation, and at sufficiently high flow rates complete mixing is attained. It has not been established whether this segregation occurs in the absence of electrostatic effects. Further studies were recommended using a conducting column and conducting particles of uniform physical properties in order to eliminate electrostatic effects. One suggestion was that the oxide coating might be removed from magnesium or aluminium particles which could then be fluidised with nitrogen to prevent reoxidation.

Are Leaky Steam Valves Inevitable?

THE general rule that water must be purged from steam lines and all connected plant is well known in principle, but installations often neglect this in practice in the way the valves are sited. This point has been emphasised by M. Stein in a recent article* discussing the causes of leaky steam valves. Wear in the valves, and consequent leakage, is often wrongly attributed to defective materials of construction, entrained particles or high steam velocity. Ing. Stein reports a number of practical examples of simple rearrangement of valves of the same material in the same relative position in the lines which have remained tight over long periods by mounting the valves in such a way as to allow drainage of condensate. U. R. Evans showed that corrosion can occur due to differential aeration and setting up of concentration cells. These conditions are likely to occur in trapped pockets of stagnant condensate. The thesis is illustrated with simple sketches of good and bad positions for location of steam valves in rising pipes from a steam manifold and also when connected to other common apparatus. The remedy seems so simple that it is difficult to believe that it has not been extensively tried. It would be interesting to know of readers' experience with valves carefully sited to avoid any trapping of condensate. Has this really prevented development of leaky valves?

* *Chaleur et Industrie*, 1957, 38, 235.

Cermets For High Temperature Uses

THE most usual response to a mention of cermets is to think of them as material for turbine blades. In fact they may help to solve problems in other conditions where high temperatures are met and impact is not a problem. According to Wambold and Frangos* chromium bonded aluminium oxide is being evaluated for furnace parts and fixtures and for melting pot components where resistance to wetting is important. Other uses are for burner parts where oxidation and thermal shock causes failure of pure oxide ceramics, in brazing fixtures where resistance to wetting is desired and for thermocouple tubes. At present the only other basic type of cermet in appreciable production is nickel alloy bonded titanium carbide. Yet cermets as a class are materials that can be fabricated to meet special requirements by suitable choice of constituents. This may be another field where the engineers will soon be able to ask for "tailor-made" properties instead of using "reach-me-down" materials.

* Wambold, J. & Frangos, T. F. *Design Engineering*, 1957, 3, No. 10, 67.

SIRA At Home

AT the first open week to be held by the British Scientific Instrument Research Association during its nearly forty years' existence, visitors from industrial, research and other organisations saw, in the Association's laboratories and information department at Chislehurst, exhibits representative of the kind of work now being undertaken. Instruments shown included an electromagnetic and an ultrasonic flowmeter, intended for use with pulsating flows, corrosive or gelling liquids, slurries, etc. The purpose of the work on the electromagnetic model is to widen the range of usefulness of that kind of instrument. Although the need for the impedance of the measuring device to be much greater than that of the fluid between the electrodes usually limits this range, the model was shown operating, in fact, with ethylene glycol. The ultrasonic flowmeter causes ultrasonic sound waves to be propagated both in and against the direction of the flow being measured. The differential time is measured as a phase difference between the signals at the receiving transducers, and the model has been designed to give a full-scale reading in the region of a flow of 20 gallons a minute in a 2-in. pipe. The system can readily be adapted, it is said, to other pipe diameters and velocity ranges. Increasing work is demanding further space for the Association's activities, and plans for extensions were exhibited.

Accident at Windscale

NOTHING less than a full and frank report would have satisfied public opinion after the accident at Windscale No. 1 Pile on 10th October. The Atomic Energy Authority have accepted full responsibility without hiding behind the direct pile operator. The immediate cause of the accident was reported to be "the application too soon and at too rapid a rate of a second nuclear heating to release the Wigner energy from the graphite, thus causing the failure of one or two cartridges in the pile. . . ." The Wigner energy is that lost by the neutrons and stored in the graphite. It is necessary to arrange a periodical release of this energy by heating the graphite above its normal working temperature. Sir John Cockcroft explained that other safer methods of performing this release are now being studied. But a further cause of the contamination of the surrounding area was evidently the failure of the filter arrangement at the top of the stack. In reply to our questions, Sir William Penney stated that the filters were very good "except for fine particles." They were not much good for vapours and normally there were no vapours. The escape of radio-iodine vapours which occurred in the accident was quite unexpected. The question of re-design is apparently going to be studied after the reports have been received from the independent committees set up under the chairmanship of Sir Alexander Fleck. It was reassuring to learn that the separate Medical Research Council investigation of the accident led to the conclusion that no harm to health is likely to have occurred.

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Chemical Engineers and the I.G.Y.

CHARACTERISTIC of the age we live in is the ever-extending control exercised by man over the forces of nature. It is an age wherein the dreams of the philosophers and scientists of the past are fast becoming realities and in which outer space, long regarded as an inpenetrable void, is now on the way to becoming a well-travelled highway. The projecting of vessels into the far heavens in a controlled manner is an engineering achievement emphasising that the frontiers to man's progress are limitless. These compelling events are associated closely with the programme of the I.G.Y. and, compared with its predecessors of 1882 and 1932, the present I.G.Y. will, without a doubt, make an immeasurably greater impact upon our lives. From the work of this vast organisation we shall learn very much more about the earth's interior, the movement of the oceans and the mineral wealth of Polar regions. Already close studies of solar-terrestial relations is under way, as well as of the ionosphere and the space beyond, and doubtless before long our understanding of cosmic radiation and its effects will advance enormously.

If some of these activities appear to be remote from an engineering view, few, if any of them, could be undertaken without the assistance of practical engineering of all kinds. Equipment such as the giant radiotelescope at Jodrell Bank and the photo Zenith tube installed at Herstmonceaux are examples of a very refined type of mechanical engineering; but the most spectacular engineering accomplishments of all are the satellite laboratories now encircling the globe. Here a number of other technologies have come together to play their special part in the construction of the space vehicles and their launching rockets. Many aspects of the materials of construction and the design of the propulsion units fall within the orbit of chemical engineering. But the most important contribution is in the production of the fuels themselves. Among the possible propellents are boron-oxygen, diborane-oxygen, hydrogen-oxygen, hydrogen-fluorine and monatomic hydrogen. In the case of the latter, the problem of low-temperature storage within and without the launching means is another aspect with which chemical engineers are not unfamiliar.

This is not to overlook the contribution made by those who designed the radar equipment for controlling the launching operations and for tracing the paths of the vehicles through the heavens, and the efforts that produced the various measuring devices and communicating instruments are similarly praiseworthy.

Interplanetary travel will involve a host of problems. Among them will be the design of low-thrust motors to drive the space vehicles once they have been projected aloft on the long haul between planets. The devices which will eventually be used may very well rely for their propulsive effort upon solar energy. A radiation-collecting system would therefore be employed in conjunction with some means for converting solar to thermal energy. Another line of research coming within the realms of feasibility is the discharge of electrical energy into an arc for the purpose of heating a working fluid before expansion through a nozzle. A further possibility is the ion motor, whose propulsive effort arises from the passage of charged particles, e.g., of cæsium, through a magnetic field.

Not only have the investigations required by the I.G.Y. themselves called for great engineering accomplishments, but indirectly many of the results obtained will put before all kinds of engineers a host of fascinating and rewarding tasks. Although the I.G.Y. does not concern itself directly with the world's problems of energy, the prominence given to sun-earth relations is a reminder of how dependent we are upon the great luminary. It is from this enormous atomic reactor that the earth receives its energy—the portion coming to us from the interior of earth is a mere twenty-thousandth of the sun's contribution.

Unlike the wise man who likes to accumulate some capital and live within his income, we have to admit that the inhabitants of earth are expending energy at a rate faster than it is being stored; thus the earth's reserves of fossil fuels are slowly and steadily being depleted. Nuclear fuels may not be the complete answer to this problem, and it may be that practicable nuclear fusion processes will require tritium and not deuterium. Man, therefore, instead of having a virtually inexhaustible source of fuel in the oceans at his disposal, would instead be limited to the deposits of lithium. What treasures may be made available through excursions to other planets cannot at present be forecast with any certainty. It seems inevitable, therefore, that new methods will be devised for absorbing more of the energy we receive from the sun and for converting this energy into useful forms. For power generation, the silicon photocell with an efficiency of more than 11% is one interesting possibility. Another line of approach is the use of photochemical reactions; some of these reactions may be reversed in the dark to yield a proportion of the energy they received initially as thermal or electrical energy.

In conclusion, an aspect of I.G.Y. most worthy of comment is the high degree of international co-operation it represents and on a scale unmatched in any other fields of human endeavour. The reason may be that the issues before astronomers and geophysicists relate more to the philosophical than to the immediately practical, but, whatever the cause, it is to be hoped that this exceptional state of affairs will in time embrace the technologies, for international isolation has few benefits.

DESIGNING AZEOTROPIC DISTILLATION COLUMNS

by S. R. M. ELLIS, Ph.D., F.R.I.C., A.M.I.Chem.E., and C. J. PEARCE, Ph.D.

In this article the authors review a number of suggested methods for the design of azeotropic distillation columns as applied to the system ethyl acetate-acetic acid-water

IN the extraction of acetic acid from water with ethyl acetate as a solvent, there is the problem of designing an azeotropic distillation column to separate the ethyl acetate and water from the acetic acid in the extract phase and so obtain acetic acid in the bottoms product. A number of methods have been suggested for the design of azeotropic distillation columns,[1, 2, 3] and so it is proposed to review some of these procedures in their application to the design of a column for the dehydration of acetic acid-water mixtures using ethyl acetate as the entrainer.

Variation in Molal Overflow

Equi-molal overflow may be approximated in a column by neglecting sensible heat effects and heats of mixing, but making Trouton's Rule constants equal for each component.[10] The latent heats of vaporisation of ethyl acetate, acetic acid and water at their boiling points are as follows[4]:

Acetic acid	...	96.75 CHU/lb. at 118.3°C
Ethyl acetate	...	87.5 CHU/lb. at 77.1°C
Water	...	540 CHU/lb. at 100°C

Trouton's Rule constants, calculated using 60.05 as the molecular weight of acetic acid, are as follows:

Acetic acid	14.8
Ethyl acetate	22.1
Water	26.0

For a molecular weight of 120 the Trouton Rule constant for acetic acid is 29.6, which approximates more closely to the values for water and ethyl acetate. Using the molecular weight of 120 for acetic acid, the ternary vapour-liquid equilibrium data[5] for acetic acid-ethyl acetate-water have been recalculated (see Table 1).

Material Balance over Column

As the overhead vapour composition is approximately equal to that of the binary azeotrope, the bottoms composition will depend entirely upon the composition of the feed to the column unless secondary reflux is used. If the column uses condensed vapour only as reflux, i.e., primary reflux, the feed composition must contain ethyl acetate and water in the ratio in which these components occur in the binary ethyl acetate-water azeotrope. If the composition of the feed was considerably different to that desired, then an extra reflux from one of the phases in the decanter would be required. For example, if the water content in the feed was to increase, a portion of the ethyl acetate phase from the decanter would have to be fed back to the azeotropic column and this is referred to as secondary reflux. It will be shown later that increasing the water content of the feed also increases the minimum reflux ratio required for the operation of the column.

In the event of primary reflux only being required, the material balance is comparatively simple. For both primary and secondary reflux, the solubility data of Garner, Ellis and Roy[6] have been used to calculate compositions and flow quantities.

In this article the following feed, bottom and top product compositions are used in the following calculations.

Mr. Ellis *is Professor of the Chemical Engineering Department of Birmingham University.* **Mr. Pearce** *is a research chemical engineer at the Esso Refinery, Fawley.*

Symbols

X_W = mole fraction of water in the liquid;
X_A = mole fraction of acetic acid in the liquid;
X_E = mole fraction of ethyl acetate in the liquid;
Y_W = mole fraction of water in the vapour;
Y_A = mole fraction of acetic acid in the vapour;
Y_E = mole fraction of ethyl acetate in the vapour;
α_{EW} = relative volatility of ethyl acetate to water;
α_{WA} = relative volatility of water to acetic acid;
α_{EA} = relative volatility of ethyl acetate to acetic acid;
$\left(\frac{X_W}{X_A}\right)_{F+1}$ = ratio of water to acetic acid on the plate above the feed plate;
$\left(\frac{X_W}{X_A}\right)_F$ = ratio of water to acetic acid on the feed plate; and
$\left(\frac{X_W}{X_A}\right)_i$ = ratio of water to acetic acid at the intersection of the operating lines.

Component	Feed		Bottoms		Ethyl acetate layer from decanter + water from stripper	
	Wt. %	Mole %	Wt. %	Mole %	Wt. %	Mole %
Acetic acid (A)	7.8	4.5	99.86	99.12	—	10^{-10}
Ethyl acetate (E)	84.65	66.46	0.0074	0.01	91.85	69.7
Water (W)	7.55	29.04	0.131	0.87	8.15	30.3

TABLE 1—VAPOUR-LIQUID EQUILIBRIUM RESULTS

Temp. (°C)	Press. (mm. Hg.)	X_W	X_A	X_E	Y_W	Y_A	Y_E	$\frac{100X_E}{X_A+X_E}$	$\frac{100X_E}{X_E+X_W}$	$\frac{100X_A}{X_A+X_W}$	α_{WA}	α_{EA}	α_{EW}
93.8	742.5	0.59	0.302	0.108	0.54	0.12	0.34	26.4	15.5	33.8	2.3	7.92	3.44
98.5	751	0.127	0.563	0.310	0.184	0.254	0.562	38.1	71.0	81.5	3.21	4.01	1.25
95.0	755	0.107	0.470	0.423	0.154	0.180	0.666	47.3	79.8	81.4	3.76	4.11	1.09
93.1	745	0.093	0.445	0.462	0.138	0.159	0.703	51.0	83.2	82.6	4.15	4.25	1.03
90.1	736	0.076	0.379	0.545	0.111	0.124	0.765	59.0	87.8	83.3	4.46	4.29	0.962
88.9	735	0.063	0.348	0.589	0.099	0.105	0.796	62.8	90.25	84.5	5.2	4.48	0.86
87.0	738	0.050	0.334	0.616	0.085	0.082	0.833	64.9	92.5	87.0	6.9	5.5	0.795
85.9	759	0.044	0.247	0.709	0.073	0.0605	0.8665	74.1	94.3	84.9	6.77	5.0	0.891
82.2	752.5	0.0264	0.153	0.8206	0.0483	0.0326	0.919	84.4	96.9	85.3	8.59	5.25	0.611
81.5	755	0.0184	0.127	0.8546	0.0402	0.024	0.9358	87.3	97.9	87.5	11.56	5.8	0.502
80.7	754	0.0155	0.107	0.8775	0.0379	0.0183	0.9438	89.1	98.3	87.5	14.3	6.28	0.439
79.1	730	0.0126	0.099	0.8884	0.0328	0.0164	0.9508	90.0	98.5	88.7	20.5	6.48	0.411
106.3	751	0.254	0.667	0.079	0.362	0.417	0.221	10.6	24.6	72.4	2.28	4.48	1.97
100.1	757.5	0.21	0.565	0.225	0.27	0.29	0.44	28.5	51.8	73.0	2.5	3.81	1.52
96.45	757.5	0.168	0.499	0.333	0.218	0.217	0.565	40.0	66.7	74.9	2.98	3.9	1.31
93.15	755	0.135	0.435	0.430	0.179	0.167	0.654	49.7	76.3	76.3	3.45	3.96	1.16
91.2	750	0.116	0.399	0.485	0.159	0.135	0.706	54.9	80.6	77.5	4.05	4.3	1.06
90.7	750	0.102	0.387	0.511	0.465	0.126	0.7275	57.0	83.3	79.3	4.42	4.37	0.99
86.8	740.5	0.186	0.328	0.486	0.217	0.0893	0.6937	59.8	72.3	63.9	4.28	5.24	1.22
86.1	740.5	0.159	0.299	0.542	0.197	0.0845	0.7185	64.5	77.5	65.3	4.39	4.68	1.07
84.35	738.5	0.124	0.258	0.618	0.167	0.0626	0.7704	70.5	83.3	67.5	5.55	5.14	0.925
83.9	738.5	0.104	0.244	0.652	0.149	0.057	0.794	72.7	86.3	70.0	6.12	5.2	0.85
82.1	734	0.075	0.199	0.726	0.124	0.388	0.8372	78.5	90.7	72.6	8.47	5.9	0.698
81.2	735	0.058	0.170	0.772	0.1035	0.032	0.8645	82.0	93.0	74.6	9.5	5.95	0.626
80.0	745	0.0374	0.119	0.8436	0.080	0.0201	0.8999	87.5	96.1	76.3	12.7	6.32	0.498
78.9	743.5	0.026	0.0856	0.8884	0.066	0.012	0.922	91.1	97.2	76.7	21.8	7.42	0.41
99.7	749.5	0.354	0.515	0.131	0.410	0.250	0.340	20.3	27.0	59.3	2.38	5.35	2.24
96.6	750	0.312	0.471	0.217	0.351	0.206	0.443	31.5	41.1	60.1	2.57	4.67	1.82
93.5	751	0.284	0.428	0.288	0.311	0.152	0.537	40.2	50.5	60.0	3.08	5.25	1.70
89.4	753	0.203	0.364	0.433	0.235	0.119	0.646	54.2	68.1	64.2	3.54	4.57	1.29
101.3	759	0.503	0.437	0.060	0.557	0.235	0.208	12.1	10.65	46.5	2.06	7.3	3.13
94.8	754	0.460	0.383	0.157	0.452	0.160	0.388	29.1	25.6	45.5	2.35	5.9	2.51
90.75	753.5	0.391	0.348	0.261	0.374	0.115	0.511	42.9	40.1	47.1	2.89	5.93	2.05
88.3	755	0.340	0.322	0.338	0.330	0.0893	0.578	51.2	50.0	48.6	3.5	6.16	1.76
86.8	753	0.301	0.305	0.394	0.302	0.0765	0.622	56.4	56.6	50.4	4.0	6.3	1.58
83.0	743	0.244	0.244	0.512	0.261	0.048	0.691	67.8	67.8	50.0	5.43	6.87	1.26
81.2	734.5	0.193	0.210	0.597	0.228	0.0374	0.735	74.0	75.5	52.2	6.64	6.91	1.04
80.9	746.5	0.159	0.185	0.656	0.208	0.031	0.761	78.0	80.5	53.8	7.8	6.92	0.887
78.9	735	0.106	0.141	0.753	0.171	0.0204	0.809	84.2	87.7	57.1	11.14	7.43	0.666
78.0	734.5	0.073	0.107	0.820	0.142	0.0152	0.843	88.5	91.8	59.5	13.7	7.25	0.529
98.2	764	0.719	0.246	0.035	0.686	0.131	0.183	12.5	5.1	25.5	1.79	9.82	5.47
93.0	763	0.663	0.244	0.093	0.555	0.0905	0.355	27.6	12.5	26.9	2.26	10.3	4.56
87.8	763	0.596	0.228	0.176	0.456	0.060	0.484	43.6	23.0	27.7	2.9	10.5	3.62
82.1	753	0.475	0.194	0.331	0.372	0.036	0.592	63.0	41.0	29.0	4.22	9.65	2.29
78.8	755.5	0.356	0.155	0.489	0.327	0.022	0.651	76.0	58.0	30.3	6.48	9.39	1.45
77.4	755.5	0.277	0.129	0.594	0.286	0.0138	0.700	32.0	68.4	31.8	9.68	11.05	1.14
76.0	750	0.186	0.094	0.720	0.245	0.0123	0.743	88.5	79.5	33.6	10.05	7.88	0.783
75.6	750	0.134	0.071	0.795	0.2105	0.0103	0.780	92.0	85.6	34.6	10.8	6.75	0.625
75.7	754.5	0.0921	0.059	0.849	0.164	0.0086	0.8274	93.5	90.3	39.0	12.2	6.7	0.549
103.25	756.4	0.204	0.620	0.176	0.280	0.349	0.371	22.1	46.4	75.3	2.44	3.74	1.54
92.2	756.4	0.861	0.1085	0.0305	0.638	0.047	0.315	22.0	3.5	11.2	1.71	23.8	13.9
99.8	748	0.410	0.467	0.123	0.460	0.230	0.310	20.9	23.1	53.3	2.28	5.11	2.25
84.0	748	0.802	0.111	0.087	0.449	0.0283	0.523	44.0	9.8	12.2	2.2	23.6	10.75
98.0	761.4	0.638	0.301	0.061	0.628	0.150	0.222	16.8	9.0	32.1	1.98	7.3	3.7
78.8	766.3	0.713	0.100	0.187	0.352	0.0158	0.632	65.2	20.9	12.3	3.12	21.4	6.85

If the composition of the liquid leaving a plate is known, the vapour composition leaving the plate is readily calculated by the method suggested by Norman.[7] Plots were made of the relative volatilities of water to acetic acid, ethyl acetate to acetic acid and of ethyl acetate to water against the composition ratios

$$\frac{100\ X_A}{X_W + X_A},\quad \frac{100\ X_E}{X_E + X_A} \text{ and } \frac{100\ X_E}{X_E + X_W}$$

using 100 X_E, 100 X_W and 100 X_A as parameters respectively. The smoothed plots are given in Figs. 1, 2 and 3.

Although the relative volatility α_{EW} is not directly useful, it may be used to obtain the values of α_{EA} and α_{WA} more accurately at low values of X_A. Either α_{EA} or α_{WA} may be known accurately, in which case the value of the other is obtained using the relation:

$$\alpha_{EW} = \frac{\alpha_{EA}}{\alpha_{WA}}$$

Having obtained the values of α_{EA} and α_{WA} corresponding to the composition of the liquid from a plate, the composition of the vapour to the plate above was calculated using the equations:

$$Y_A = \frac{1}{1 + \alpha_{EA} \cdot \frac{X_E}{X_A} + \alpha_{WA} \cdot \frac{X_W}{X_A}}$$

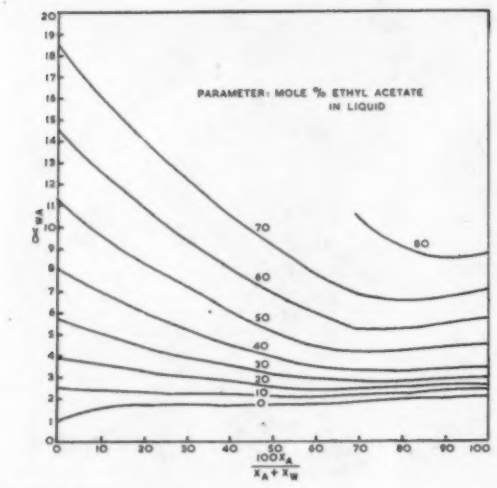

Fig. 1. Relation between relative volatility of water to acetic acid and liquid composition.

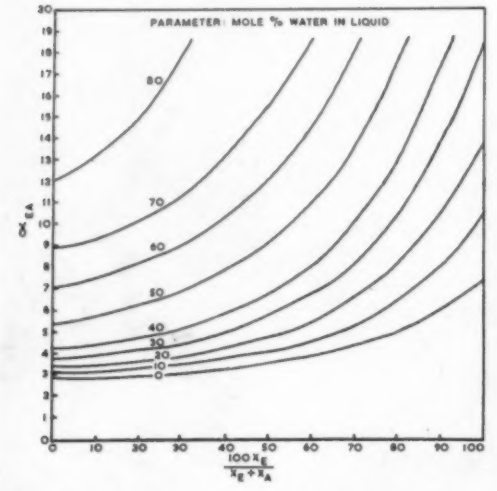

Fig. 2. Relation between relative volatility of ethyl acetate to acetic acid and liquid composition.

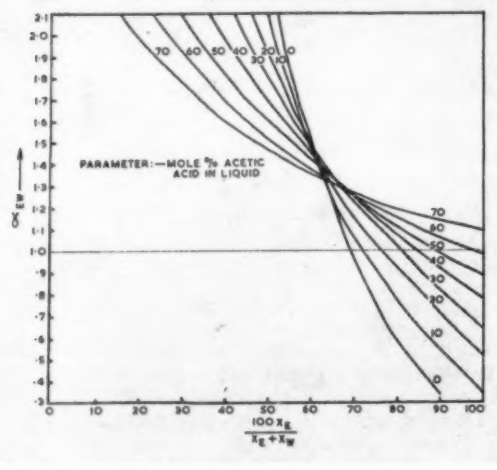

Fig. 3. Relation between relative volatility of ethyl acetate to water and liquid composition.

$$Y_W = \alpha_{WA} \cdot \frac{X_W}{X_A} \cdot Y_A$$

$$Y_E = \alpha_{EA} \cdot \frac{X_E}{X_A} \cdot Y_A$$

This procedure was used in the plate-to-plate calculations to determine the minimum reflux ratio and the number of plates required for a given separation.

Minimum Reflux Ratio

Due to the variation of the relative volatilities of the components in an azeotropic distillation column, the methods for estimating the minimum reflux ratios for ideal or near-ideal systems are inapplicable. The "pinch composition", at which the vapour from a plate is in equilibrium with the liquid to that plate, does not necessarily occur at the intersection of the operating lines. For this reason the feed-plate composition need not be equal to the composition of the feed.

The methods recommended by Robinson and Gilliland,[8] Norman[7] and Pratt[9] have been used to estimate the minimum reflux ratio conditions. These methods give a minimum liquid-to-vapour ratio in the stripping section of 1.04 and in the rectifying section of 0.12 for the feed, bottoms and top product compositions given above.

Feed-plate Location

The method suggested by Gilliland[8] for feed-plate location was used as a first approximation. The condition at the feed plate in a multi-component distillation column is

$$\left(\frac{X_W}{X_A}\right)_{F+1} > \left(\frac{X_W}{X_A}\right)_1 > \left(\frac{X_W}{X_A}\right)_F$$

for a wholly liquid feed at its boiling point. This does not necessarily give the optimum feed point for an azeotropic distillation column, and so the feed has been introduced on to the lowest plate in the stripping section so that normal enrichment continues in the rectifying section.

Minimum Plates at Total Reflux

Using the feed and product compositions given previously, the number of plates required for the separation at total reflux was calculated. The plate compositions are given in Table 2. It is to be noted that the ratio of acid to water between trays 8 and 9 approaches the feed ratio, and that above trays 8 and 9, corresponding to the rectifying section, the change in concentration of water and ethyl acetate is small.

Operating Reflux Ratio

The calculations were repeated using the same top, bottoms and feed compositions for a number of reflux

TABLE 2—PLATE ANALYSIS AT TOTAL REFLUX

Plate	X_A	X_W	X_E	Y_A	Y_W	Y_E
Still	0.9912	0.0087	0.0001	0.982	0.01815	0.0002
1	0.982	0.01815	0.000291	0.962	0.0373	0.0008
2	0.962	0.0373	0.000843	0.923	0.0745	0.0024
3	0.923	0.0745	0.00242	0.852	0.141	0.0069
4	0.852	0.141	0.0069	0.737	0.244	0.0191
5	0.737	0.244	0.0191	0.577	0.370	0.0538
6	0.577	0.370	0.0538	0.382	0.465	0.153
7	0.382	0.465	0.153	0.16	0.456	0.384
8	0.16	0.456	0.384	0.0224	0.332	0.6455
9	0.0224	0.332	0.6455	0.00135	0.299	0.6996
10	0.00135	0.299	0.6996	0.0000743	0.2995	0.7004
11	0.0000743	0.2995	0.7004	4.04×10^{-6}	0.300	0.700
12	4.04×10^{-6}	0.300	0.700	2.2×10^{-7}	0.301	0.699
13	2.2×10^{-7}	0.301	0.699	1.2×10^{-8}	0.302	0.698
14	1.2×10^{-8}	0.302	0.698	6.53×10^{-10}	0.303	0.697
15	6.53×10^{-10}	0.303	0.697	3.55×10^{-11}	0.303	0.697

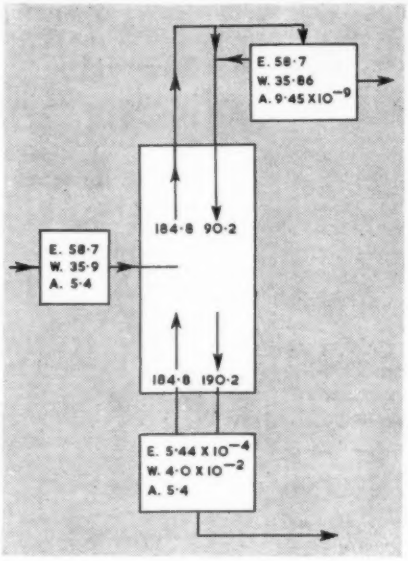

Fig. 4 (left). Material balance for reflux ratio of 0.33.

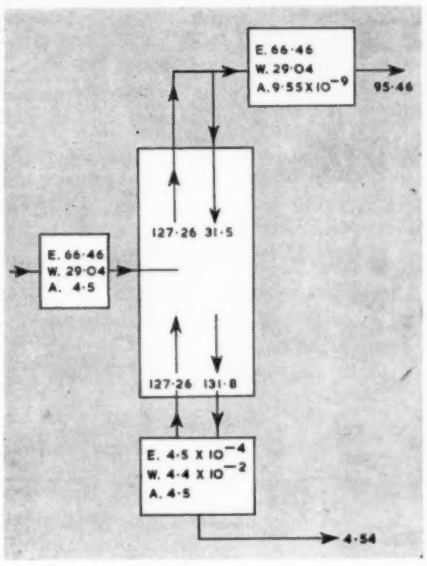

Fig. 5 (right). Material balance for reflux ratio of 0.95.

ratios. The results obtained for a primary reflux ratio of 0.333 are given in detail in Table 3. The molal flow quantities are given in Fig. 4.

It will be noticed from Table 3 that the concentrations of ethyl acetate and water are fairly constant above the feed plate and approximate to the values in the binary azeotrope. The main feature of the separation in the rectifying section is to remove acetic acid from the overhead product.

The effect of change of reflux ratio is shown in Table 4. The vapour quantities given are based on 100 moles of feed. The number of plates in the rectifying section increased quite rapidly with decrease in reflux ratio. The number of plates in the stripping section increased far less rapidly.

Feed Composition

In order to consider the effect of variation of feed composition upon the reflux ratio required, the following example was considered. The bottoms composition used was approximately the same as in the previous examples. The feed composition, overhead product and molal flow quantities are given in Fig. 5. The minimum reflux ratio for this separation was found to be 0.5, a considerable increase on the value required previously.

In the example given below an overflow/vapour ratio of 0.488 was used for the rectifying section. This corresponds to a reflux ratio of 0.95. The solubility data at 30°C were used to calculate the material balance. The plate-to-plate analysis is given in Table 5.

The column requires a total of 18 plates with the feed introduced on plate 9 from the bottom of the column. This indicates that the separation could be carried out, but only if the reflux ratio is considerably increased and a secondary reflux is used from the ethyl acetate phase in the decanter. The required number of plates and the reflux ratio are thus sensitive to the feed composition.

TABLE 3—TRAY ANALYSES FOR REFLUX RATIO OF 0.333

Plate	X_A	X_W	X_E	Y_A	Y_W	Y_E
Still	0.9912	0.0087	0.0001	0.982	0.01815	0.000291
1	0.983	0.01785	0.000284	0.9624	0.0368	0.000821
2	0.9634	0.0359	0.000797	0.926	0.0718	0.00228
3	0.930	0.0675	0.00221	0.865	0.129	0.00629
4	0.870	0.125	0.00609	0.7625	0.2202	0.0172
5	0.772	0.213	0.0166	0.615	0.338	0.046
6	0.629	0.327	0.0445	0.437	0.439	0.124
7	0.457	0.424	0.120	0.232	0.458	0.311
8	0.258	0.443	0.301	0.06	0.374	0.566
9	0.092	0.362	0.547	0.00828	0.303	0.689
10 FP.	0.042	0.293	0.666	0.00295	0.292	0.705
11	0.0118	0.257	0.732	0.000728	0.295	0.705
12	0.00291	0.269	0.732	0.000168	0.299	0.7008
13	0.000672	0.285	0.715	3.75×10^{-5}	0.302	0.698
14	1.5×10^{-4}	0.296	0.704	8.21×10^{-6}	0.303	0.697
15	3.29×10^{-5}	0.303	0.697	1.77×10^{-6}	0.303	0.697
16	7.075×10^{-6}	0.303	0.697	3.81×10^{-7}	0.303	0.697
17	1.525×10^{-6}	0.303	0.697	8.19×10^{-8}	0.303	0.697
18	3.27×10^{-7}	0.303	0.697	1.76×10^{-8}	0.303	0.697
19	7.04×10^{-8}	0.303	0.697	3.78×10^{-9}	0.303	0.697
20	1.51×10^{-8}	0.303	0.697	8.12×10^{-10}	0.303	0.697
21	2.95×10^{-9}	0.303	0.697	1.59×10^{-10}	0.303	0.697
22	3.3×10^{-10}	0.303	0.697	$<10^{-10}$	0.303	0.697

Comparison of Methods

It is now proposed to compare the tray-to-tray analysis results in Table 3 with those obtained by graphical construction.

Modified Chambers' Method

The method of Chambers[2] is rather similar to the McCabe-Thiele method for binary systems. The ternary data are expressed on two plots which are used alternately to step off the plates.

The Y-X plots of acetic acid and water were used as shown in Figs. 6 and 7. A stepwise solution was obtained by stepping off the plates alternately in Figs. 6 and 7. In this problem these graphical constructions apply only to the stripping section. This is because in the rectifying section the change in concentration of acetic acid from plate to plate is small, and the use of Chambers' method

TABLE 4—VARIATION OF REFLUX RATIO AND NUMBER OF PLATES

Vapour (moles)	*Reflux ratio*	*Plates below and including feed plate*	*Plates above feed plate*	*Total plates*
—	∞	—	—	15
127.3	0.333	10	12	22
116.7	0.223	10	15	25
112.3	0.177	11	17	28
106	0.12	∞	∞	∞

is not sufficiently sensitive to show these small changes in acetic acid concentration.

It has already been noted, both in the case of total reflux and of reflux ratios of 0.33 and 0.95, that the change in concentration of water and ethyl acetate above the feed plate is small. It is thus possible to design the rectifying section by calculating the number of equilibrium stages using a log *vs.* log construction as shown in Fig. 8. The concentration of acetic acid in the vapour of the ternary mixture is plotted against the corresponding concentration of acetic acid in the liquid phase. Assuming the water content of each phase to be constant, the change in concentration of acetic acid and ethyl acetate is readily determined.

The plate liquid compositions obtained by this combination of graphical methods compare favourably with those obtained by plate-to-plate analysis. The number of plates obtained by each method is the same, namely, 22.

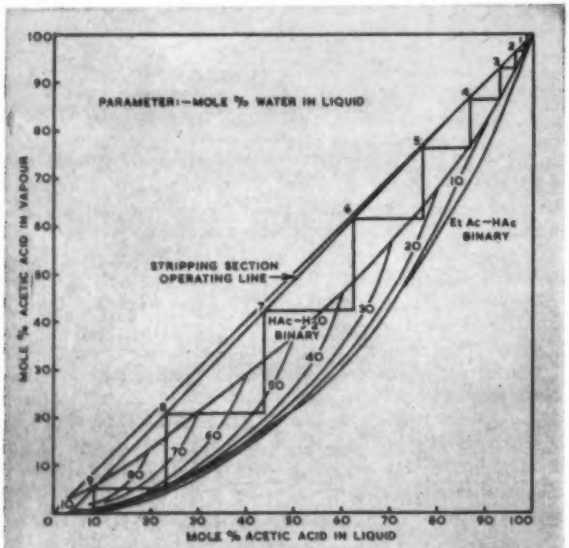
PARAMETER:—MOLE % WATER IN LIQUID
Et Ac—HAc BINARY
STRIPPING SECTION OPERATING LINE
HAc—H2O BINARY
MOLE % ACETIC ACID IN VAPOUR
MOLE % ACETIC ACID IN LIQUID

Fig. 6. y-x diagram used in Chambers' method with Fig. 7.

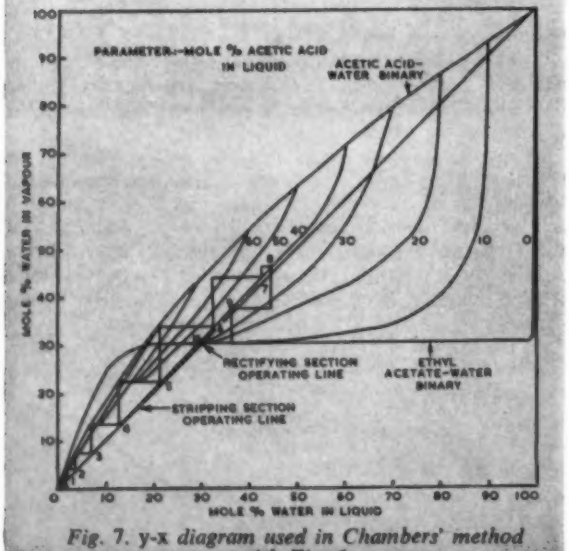
PARAMETER:—MOLE % ACETIC ACID IN LIQUID
ACETIC ACID–WATER BINARY
RECTIFYING SECTION OPERATING LINE
ETHYL ACETATE–WATER BINARY
STRIPPING SECTION OPERATING LINE
MOLE % WATER IN VAPOUR
MOLE % WATER IN LIQUID

Fig. 7. y-x diagram used in Chambers' method with Fig. 6.

TABLE 5—TRAY ANALYSES FOR REFLUX RATIO OF 0.95

Plate	X_A	X_W	X_E	Y_A	Y_W	Y_E
Still	0.9926	0.00735	0.0001	0.984	0.0153	0.00029
1	0.985	0.01505	0.000285	0.9675	0.03105	0.00085
2	0.968	0.03035	0.000828	0.9375	0.0611	0.00239
3	0.938	0.0595	0.00232	0.880	0.114	0.0066
4	0.882	0.111	0.00641	0.782	0.200	0.0182
5	0.788	0.1945	0.0176	0.635	0.315	0.0483
6	0.645	0.306	0.0469	0.453	0.419	0.1282
7	0.468	0.406	0.1255	0.239	0.447	0.314
8	0.2605	0.434	0.305	0.0605	0.373	0.566
9 FP.	0.0870	0.362	0.550	0.00901	0.359	0.632
10	0.01865	0.337	0.643	0.0011	0.298	0.701
11	0.00226	0.212	0.785	0.000142	0.291	0.710
12	0.000291	0.198	0.802	1.9×10^{-5}	0.2915	0.7085
13	3.91×10^{-5}	0.199	0.801	2.54×10^{-6}	0.2925	0.7075
14	5.2×10^{-6}	0.201	0.799	3.3×10^{-7}	0.296	0.704
15	6.76×10^{-7}	0.208	0.792	4.21×10^{-8}	0.299	0.701
16	8.64×10^{-8}	0.215	0.785	5.3×10^{-9}	0.300	0.700
17	1.065×10^{-8}	0.216	0.784	6.55×10^{-10}	0.301	0.699
18	1.126×10^{-9}	0.2185	0.7815	6.82×10^{-11}	0.302	0.698

TABLE 6—TRAY ANALYSES BY GRAPHICAL METHOD

Plate	X_A	X_W	X_E	Y_A	Y_W	Y_E
Still	0.991	0.0087	Trace	0.983	0.018	Trace
1	0.982	0.018	Trace	0.963	0.038	Trace
2	0.963	0.038	Trace	0.928	0.072	Trace
3	0.929	0.07	0.001	0.864	0.129	0.007
4	0.868	0.0126	0.006	0.761	0.220	0.019
5	0.768	0.214	0.018	0.613	0.338	0.049
6	0.625	0.328	0.047	0.422	0.440	0.138
7	0.440	0.426	0.134	0.207	0.462	0.331
8	0.232	0.446	0.322	0.052	0.377	0.571
9	0.083	0.362	0.555	0.008	0.302	0.690
10	0.042	0.293	0.665	0.003	0.303	0.667
11	0.0125	0.303	0.685	0.00074	0.303	0.696
12	0.003	0.303	0.694	0.000165	0.303	0.697
13	0.00067	0.303	0.696	0.000036	0.303	0.697
14	1.5×10^{-4}	0.303	0.697	8×10^{-6}	0.303	0.697
15	3.2×10^{-5}	0.303	0.607	1.7×10^{-6}	0.303	0.697
16	6.8×10^{-6}	0.303	0.697	3.6×10^{-7}	0.303	0.697
17	1.4×10^{-6}	0.303	0.697	7.4×10^{-8}	0.303	0.697
18	2.9×10^{-7}	0.303	0.697	1.55×10^{-8}	0.303	0.697
19	6×10^{-8}	0.303	0.697	3.3×10^{-9}	0.303	0.697
20	1.3×10^{-8}	0.303	0.697	7×10^{-10}	0.303	0.697
21	2.6×10^{-9}	0.303	0.697	1.45×10^{-8}	0.303	0.697
22	2.8×10^{-10}	0.303	0.697	$<10^{-10}$	0.303	0.697

The plate compositions for the above graphical construction are given in Table 6.

Method of Bakowski and Treszczanowicz[3]

In this method it is assumed that the ratio of the components forming the binary azeotrope is the same on each plate and equal to the ratio of these components in the binary azeotrope. By further assuming a straight distillation line, the system is then treated as a two-component system, one component being the binary azeotrope and the other the third component in the system. In this instance the system is assumed to consist of the ethyl acetate-water azeotrope and acetic acid.

It will be noticed from Table 3 that this is a fair assumption in the rectifying section of the column, but might lead to error in the stripping section. In the stripping section the ethyl acetate concentration increases far more rapidly than the water concentration, and hence the ratio of ethyl acetate to water in the bottoms is very different to the ratio of these components in the ethyl acetate-water azeotrope.

Fig. 9 is for the binary system acetic-acid azeotrope and it can be seen that the number of theoretical trays in the stripping section is 7 to 8 compared with 10 on Fig. 6 and 10 in Table 3. The method for the ethyl acetate-water system is thus inaccurate for the stripping section.

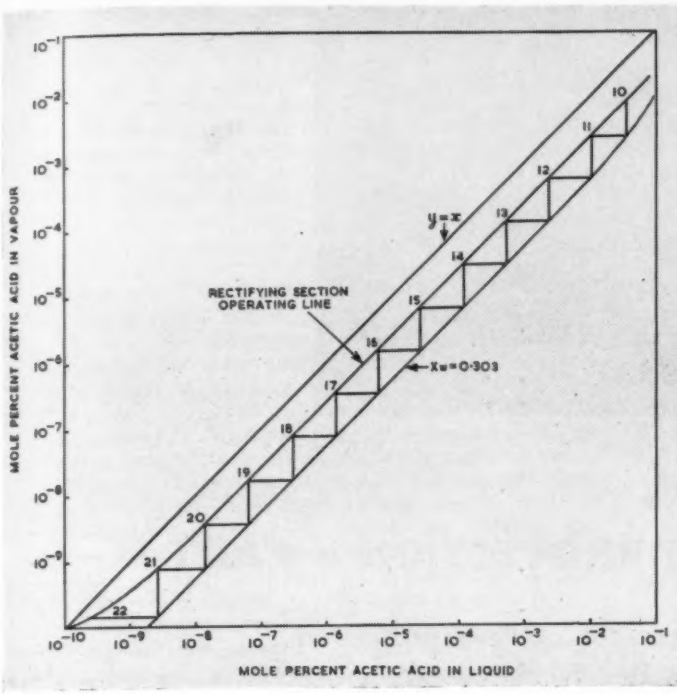

Fig. 8. Diagram for design of rectifying section.

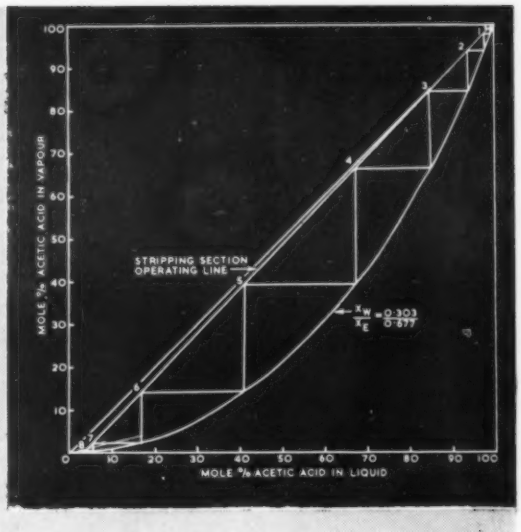

Fig. 9 (above). y-x diagram used in method Bakowski and Treszanowicz.

Conclusions

For the system ethyl acetate-acetic acid-water the most reliable method is that of tray-to-tray analysis. The method is, however, time-consuming and, as an alternative procedure, results can be determined both accurately and more rapidly by using the method of Chambers for the stripping section and a log *vs.* log construction for the rectifying section. The limiting of Chambers' method to the stripping section is necessitated by the small plate-to-plate charges in concentration of acetic acid in the rectifying section. An alternative method is to start from the reboiler and use tray-to-tray analysis to just above the feed plate; when it is noted that the water and ethyl acetate concentrations are relatively constant, the calculations can be completed using a log *vs.* log plot for acetic acid.

From examples given, it can be seen that the column may be operated with a very low reflux ratio, provided that the composition of the feed is carefully regulated. Any slight alteration in the ratio of ethyl acetate to water in the feed will require a large increase in reflux ratio to maintain the specified compositions of the products with a corresponding increase in operating costs.

In the examples above, constant molal overflow has been assumed. In the rectifying section of the column, this is likely to be so, since the composition change from the feed plate to the top plate in the column is very small. In the stripping section the variation of overflow rate will make the separation more difficult than that indicated above. The solutions are easily corrected by the use of Gilliland's method of employing average molal latent heats.[8]

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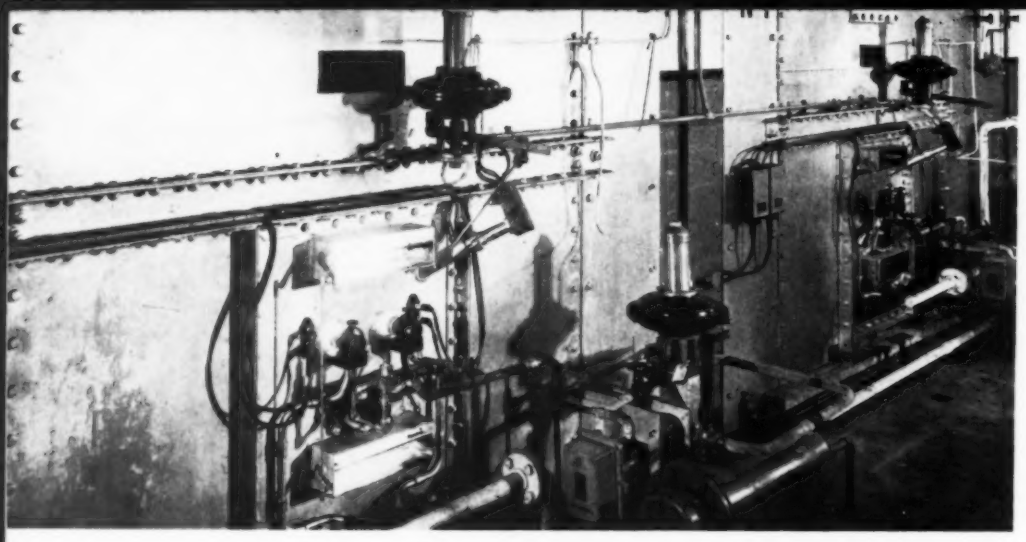
Scientific Film Congress at Amsterdam

MORE THAN TWO HUNDRED delegates representing some twenty countries were present at the Eleventh Congress of the International Scientific Film Association held recently in Amsterdam. During the Congress 180 films were shown, including ten from Great Britain, three of which related to the subject of atomic energy.

The Russian delegation put forward the suggestion that the Association should bring its committees into accordance with the main directions of scientific filming under such headings as the popularisation of science, education and research. The delegation felt that it was time a definite decision was made on this matter in view of the fact that all modifications would have an essential influence on future work. The sessions on the research film held during the Congress did reveal some confusion on the true definition of a film designed specifically for research. Many people who attended these sessions expressed the view that a research film is one in which the film is the actual means by which the research is done, and in which the film is the only or the best tool. In addition, it was felt that the film must be a record of a piece of research, usable in teaching, information and the dissemination of science by means of the cinema and the newer medium of mass appeal, television.

Mrs. Helen Coppen, of the Institute of Education, London University, who led the strong British delegation, presented a paper to the Congress on "The Quality of Films for the Popularisation of Science".

Monsieur Luc Haesaerts, of Belgium, was a popular choice as President of the Association for 1957/8, and it was decided that the 1958 Congress of the Association should be held in Moscow.



Furnace fronts of Hygrotherm T.A.S. Heaters showing oil burners and flame failure equipment as installed at Monsanto Chemicals Ltd., Newport.

LATEST DEVELOPMENTS IN

FLAME FAILURE PROTECTION — PART I*

This report reviews the types of flame-protection devices at present available, their virtues and inherent weaknesses and how each type may be best employed

General

1.1 INTRODUCTION

This review was first published in 1950 under the title "Flame-failure Devices—A Review of the Present Position"; during the time which has since elapsed, the technique of flame failure protection has developed sufficiently to warrant this revision. This second edition (Report No. 611/56, published in October, 1956, by the Industrial Gas Development Committee of the Gas Council and amended in September, 1957) therefore supersedes the previous one. This report is reproduced in full below.

In the meanwhile, I.G.D.C. Report No. 538/53, D 034 "Ancillary Equipment for the Operation and Control of Gas Heated Plant—A Review of the Present Position", has been prepared as a companion to the present document.

It also contains a list of the facts which, it is felt, manufacturers of flame-failure devices should provide for the benefit of their customers. The report contains recommendations for the correct installation of the various devices. These recommendations represent the minimum standard which should be attained by all installations with the equipment at present available. With advances in reliability and speed of response, together with a reduction in cost of the fundamentally more satisfactory devices, a progressive improvement in this standard may be looked for. There has, in particular, been considerable development in the field of multi-burner protection, and this subject is now fully considered.

It is to be clearly understood that this document refers to industrial gas practice only.

1.2 OBJECT IN PROVIDING FLAME-FAILURE DEVICES

A satisfactory flame-failure device should ensure:

(a) correct lighting procedure; and

(b) protection against flame failure from any cause.

Two-thirds of explosions occurring in gas-heated industrial equipment are associated with the lighting-up operation, a fact which is brought out in Table II of the Appendix to the Memorandum "Safety in Design and Operation of Gas Heated Ovens and Furnaces", published by the Factory Department (H.M.S.O. Form 1856, June, 1955).

1.3 INDISPENSABLE CHARACTERISTICS

The gas industry considers that any flame-failure device that does not comply with each of the following requirements is unsatisfactory.

Every flame-failure device must:

(a) entirely prevent gas from being supplied to the main burner until the pilot flame is established;

(b) if fitted correctly, be free from an inherent weakness in design which will give rise to failure to danger;

(c) after flame failure, completely stop all gas flow to the appliance, and require manual resetting;

(d) be actuated only by a properly established pilot flame sited to ignite the main burner without failure or delay. It is appreciated that this is dependent on correct installation as well as on correct design; and

(e) where it incorporates a gas-carrying component, have an approved capacity within a permitted pressure loss.

1.4 DESIRABLE FEATURES

In addition, there are a number of features which are desirable in any flame-failure device. Although not so directly connected with the primary function of the device as those listed above, they are requirements which are generally desirable in order to ensure that the device will in all cases be a practical success. Each of these requirements is listed as the result of experience, although in individual cases it may be found possible to dispense with the need to conform to every one of them.

* Owing to length considerations, Section 3 on Thermoelectric Devices will be published in the January, 1958, issue.

Every flame-failure device should:

(a) be mechanically satisfactory and readily maintained;

(b) as far as practicable be protected against adjustment by unauthorised persons;

(c) tolerate reasonable fluctuation in gas pressure and combustion characteristics;

(d) be reasonably unaffected by foreign matter;

(e) tolerate reasonable variations in ambient temperature and air speed; and

(f) tolerate reasonable vibration and mechanical shock.

1.5 INFORMATION REQUIRED FROM MANUFACTURERS

In order that those responsible for the purchase and installation of flame-failure devices have sufficient information, the manufacturer of the device should state the following facts:

(a) gas rate (for a gas of sp. gr. 0.5) through any gas valve integral with the device, at a pressure loss of 0.3 in. w.g. Since such components are normally tested with air flow, Table 1, which sets out the minimum acceptable flow rates for the various nominal sizes, gives specified air flow rates which the valve under test must pass within the permitted pressure loss, together with the approximate equivalent flow of gas of specific gravity 0.5 at the same pressure loss;

(b) where gas pressure is a factor in the operation of the device, the minimum inlet pressure at which it will work and the effect of varying pressures on its operation;

(c) minimum frequency for replacement of expendable parts; and

(d) instructions in writing for installation and servicing.

TABLE 1—Minimum Gas Rates to be passed by Gas-carrying Components of Flame-failure Devices and their Ancillaries.

Nominal Size B.S.P. (in.)	Minimum Flow Rates in cu. ft. per hr. at S.T.P. for 0.3 in. w.g. pressure drop	
	Air	Gas (sp. gr. 0.5)
$\frac{1}{8}$	11	16
$\frac{1}{4}$	28	40
$\frac{3}{8}$	50	70
$\frac{1}{2}$	85	120
$\frac{3}{4}$	140	200
1	240	340
$1\frac{1}{4}$	370	520
$1\frac{1}{2}$	530	750
2	890	1,250
$2\frac{1}{2}$	1,450	2,050
3	2,080	2,950
4	3,600	5,100
6	7,950	11,300

Note 1: The figures in this table were obtained by treating the components as an orifice of the same diameter as the actual internal diameter of the corresponding B.S. pipe with discharge coefficient 0.3. This provides a self-consistent set of figures which corresponds with good practice at the time of writing.

Note 2: This table will be found to agree with that given in B.S. 1963: 1953, "Pressure-operated Relay Valves for Use with Town Gas".

1.6 TYPES AT PRESENT IN USE

1.6.1 THERMAL EXPANSION

1.6.1.1. *Unimetallic*

These are devices in which the heat from a pilot burner causes differential longitudinal expansion between the two sides of a tubular metallic element, thus producing a small curvature of the axis of the tube. Two advantages claimed for this system are:

(a) only the temperature difference between the two sides of the tube causes the operative displacement and therefore the device should not be affected by high ambient temperatures; and

(b) on flame failure it is only necessary for the temperature difference between the two sides of the tube to disappear, which takes place largely by conduction. The device is thus rapid in response.

1.6.1.2. *Bimetallic*

Under this heading are included two types, the one depending on differential longitudinal expansion between a rod and a tube surrounding it, the two being of different materials, and the other in which differential expansion of the two components of a bimetallic strip or disc causes a change in curvature.

The inherent disadvantages of bimetallic elements are:

(a) slowness of reaction;

(b) failure due to fatigue; and

(c) limited working life.

There is the additional fact that several devices of this type do not protect the pilot and therefore do not comply with Indispensable Characteristic (c), Section 1.3.

Devices of these types are, in general, cheap and mechanically simple, and therefore have as their field those applications where speed of operation is not at a premium.

They are at present regarded as acceptable for appliances of limited gas rate, provided:

(a) the pilot is protected;

(b) *they are constructed so as to fail to safety*—not all those at present in use satisfy this condition; and

(c) they are regularly maintained, with a specific period of renewal of the bimetallic element. Renewal every six months is suggested, or more frequently depending on conditions of use.

In view of what has been said, replacement of the bimetallic elements must be made simple.

Bimetallic strips, which operate by flexure, are the least satisfactory members of this group, since the direct heating of the bimetallic material is always prone to engender corrosion, and this in turn to result in the device failing to danger. The future elimination of this source of trouble seems unlikely, and the gas industry will not encourage the use of devices which are based upon this principle. Discs of bimetallic material, when employed, are rather more satisfactory, in that they are not usually subjected to flame impingement and therefore conditions are less rigorous. Those devices dependent on differential longitudinal expansion of rods and tubes are more satisfactory owing to their more robust construction, and to the fact that the outer tube can be made of, or sheathed in, heat-resistant material.

1.6.1.3 *Liquid and Vapour Expansion*

In these devices the gas way is closed by a valve attached to a bellows which reacts to the expansion of liquid or vapour contained in a bulb connected to the bellows by a capillary tube. These devices are likely to have similar characteristics to thermoelectric devices which are dealt with in Section 1.6.2. The most important differences are that the valve does not close with a snap action, and that it is opened by the heating of the sensitive bulb without the aid of a press button. Shut-down after flame failure is a little slower than for thermoelectric devices. Insufficient experience is available to enable the reliability of

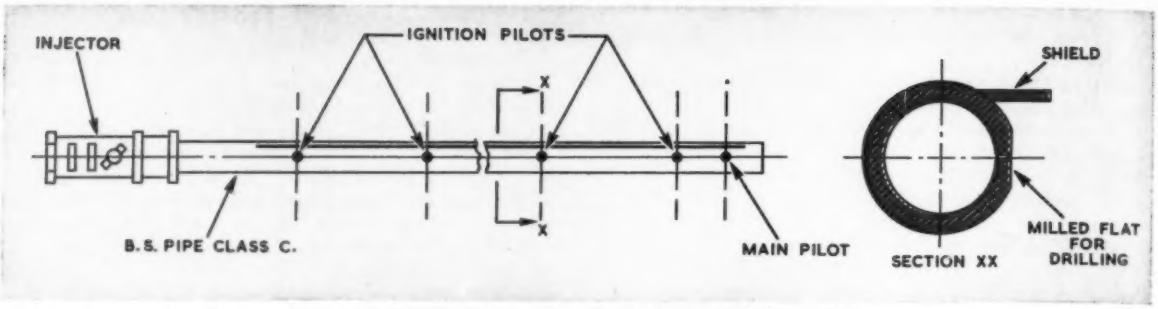


Fig. 1.1. *North Eastern Gas Board type of ladder pilot.*

these devices to be properly judged. There is no evidence yet that this principle is unsound where moderate speeds of response are acceptable.

1.6.2 THERMOELECTRIC

These devices are more sure in operation than those discussed in the previous section. They are slower in reaction than is really desirable, but they afford a compromise between cost and speed of reaction which makes them suitable for many installations of average size, where the hazards involved in flame failure are not too great. Occasional renewal of the thermocouples is necessary, and it is recommended that these be examined at least once a year, and renewed if necessary.

The devices are of two types, one having a gas valve mechanism directly attached to the keeper of the magnet, the other using the magnet to operate an electric switch which can be connected in circuit with solenoid valves, etc., in a suitable manner. The latter type can be used only where a suitable electric supply is available. Any progress toward decreasing the response time without materially affecting the cost would add considerably to the utility of this type of device.

1.6.3 ELECTRONIC

This class comprises devices utilising flame conduction or flame radiation and may be extended in the future to include the use of flame rectification and flame capacitance. All are characterised by the employment of electronic amplification and are normally operated from a 200-250 volt A.C. supply. It is therefore essential that the units should be unaffected by reasonable fluctuation in supply voltage and frequency.

In general, such devices are the most satisfactory at present available; their response is rapid and failure due to almost any cause results in a safe condition. They have the further advantage of affording provision for automatic and foolproof ignition. Their disadvantages are high cost and the need to have electric power available. Their use is, therefore, normally on large equipment, or where the hazards involved are great, or where the value of the work which may be spoiled is high. Particular care must therefore be taken that suitable ancillary equipment is used, so that the virtues of the electronic device are not wasted; this point is dealt with more fully below.

As a class, electronic flame-failure devices are reliable and have advantages over the other types which have so far been developed. Failure to danger by reason of internal faults in the amplifier and relay assembly is extremely unlikely. The electronic valves are a possible source of trouble, since there are a number of faults which can occur, and routine tests of the operation of the equipment are necessary to establish that these components are in good order. Spare valves, etc., should be kept to enable speedy replacement to be made. It may, in general, be said that the amplifier and relay are as safe as any piece of apparatus can be.

1.6.3.1 *Flame Conduction*

Early devices of this type could fail to danger if a leakage path of substantially the same resistance as that normally provided by the flame were formed. Such a leakage path can occur if a deposit of dust or condensation of a certain character forms on the electrode insulator, and experience has now shown this to be a real source of danger. Devices of this type are now available in which this possibility of failure to danger has been eliminated. Any such device not embodying this improvement cannot be regarded as satisfying Indispensable Characteristic (b), Section 1.3.

It is also possible that in a dusty situation the resistance of the flame may be so reduced as to cause the device to cut out, closing down the appliance, because a leakage path of too low resistance is formed. This, although safe, is inconvenient if it is likely to occur at all frequently, and suggests that in dusty locations it may be wise to consider an alternative such as the photoelectric device. Regular cleaning of the electrode and its insulator is necessary for all installations.

1.6.3.2 *Photoelectric*

Photoelectric devices avoid all contact with the flame, or with any very hot object; this eliminates the need to search for heat-resisting materials. A deposit of dust on the receiving lens cannot cause failure other than to safety. They need, however, to be selective to the radiation from the flame itself and this requirement is not easy to fulfil. The only satisfactory way in which this has been done is to detect the fluctuation in the infra-red radiation rather than the presence of a certain wavelength. Photoelectric cells must be subject to regular inspection, with renewal if necessary, in the same manner as thermionic valves.

1.6.3.3 *Flame Rectification and Flame Capacitance*

Flames have, in addition to the electrical properties used in the above types of device, the ability to effect partial rectification of an alternating current. Flame failure devices based on this principle are not yet in general use in this country. Another possibility is to make use of the capacitance of the flame. At present there is no experience of such a system.

1.7 PROTECTION OF MULTI-BURNER SYSTEMS

There is considerable progress to record in this branch of burner protection, both in the development of suitable protective devices and the evolution of satisfactory protective systems. The present policy of the Industrial Gas Development Committee is as follows:

(a) the ultimate aim is to eliminate the use of multi-burner systems wherever practicable;

(b) where multi-burner systems are essential, an arrangement whereby each burner is independently protected is theoretically the best. A further advantage is that it is possible to arrange such systems so that flame failure at one burner does not cause the other burners

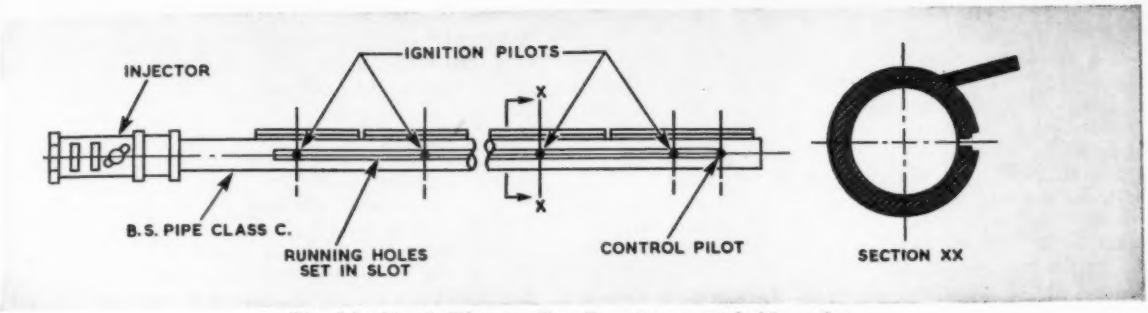


Fig. 1.2. North Thames Gas Board type of ladder pilot.

to shut down; these will remain alight, and under thermostatic or other control; and

(c) multi-burner systems protected by a ladder pilot installed in an approved manner, although not theoretically as sound as (b) above, are, in present practice, acceptable. They have the disadvantage of liberating heat in a place and at times when it is not required, and there remains a remote possibility that partial blockage of the run of the ladder will leave one or more burners unprotected.

1.7.1 DESIGN OF LADDER PILOTS

Ladder pilot burners fall into two classes which may be termed the slot type and the multi-hole type. Both may be aerated or post-aerated. The problems involved in the designs of ladder pilots may be summarised as follows:

(a) it is difficult to keep the heat release per unit length of a post-aerated ladder pilot sufficiently low;

(b) slot-type burner flames are less resistant to draughts than those from multi-hole burners;

(c) aerated slot-type burners depend upon accurate maintenance of the slot width, which is difficult over any appreciable length; and

(d) aerated multi-hole burners must have many small holes which are relatively difficult to drill and more susceptible to blockage than the slot type.

A multi-hole type of ladder pilot burner developed by the North Eastern Gas Board is shown in Fig. 1.1. The burner consists of a row of No. 60 Morse (0.040 in.) drillings at 0.08 in. spacing, with larger drillings of $\frac{3}{32}$ to $\frac{3}{16}$ in. spaced along the line of the smaller ports. These larger drillings are arranged to correspond with the axes of the main burners. For ease of drilling, the tube from which the burner is made is milled flat along the line of the drillings. A flat shield projects from the burner over the line of drillings to prevent blockage of the burner ports by substances dripping on to it. Fig. 1.2 shows a similar type of multi-hole ladder pilot burner developed by the North Thames Gas Board.* No. 53 (0.0595 in.) Morse drillings spaced not more than $\frac{3}{16}$ in. apart are used and are recessed into the burner by a milled slot to ensure that the flame runs along the burner.

A post-aerated slot type of ladder pilot burner in which the problems of excessive heat release have been overcome is shown in Fig. 1.3. Gas flows from the inner tube through a line of small holes to the annulus formed by the outer tube and burns along the slot which is diametrically opposite the line of inner holes. Larger holes are drilled, as required, through the slot and the inner tube to provide ignition flames for the main burners.

The gas rates of the three types at a gas pressure of 2.5 in. w.g. are approximately:

N.E.G.B. pilot burner		6	cu. ft per hr per ft
N.T.G.B.	„	9	„ „ „ „ „ „
Slot type	„	1.5	„ „ „ „ „ „

These figures relate to the ladder flame only, and take no account of the gas consumed by the ignition flames for the main burners.

Where ladder pilot burners are used, it is essential that:

(a) they are made of a material which will be mechanically strong under the operating temperature conditions and is not liable to corrode by action with the air-gas mixture or the products of combustion;

(b) they are securely and correctly located in relation to the main burners and at the same time protected from falling deposits or other matter; and

(c) the sensing element of the flame-failure device is securely and correctly located with respect to the ladder pilot at the end opposite to that at which the pilot will be lit. This ensures a lighting-up procedure which will check the continuity of the ladder pilot flame.

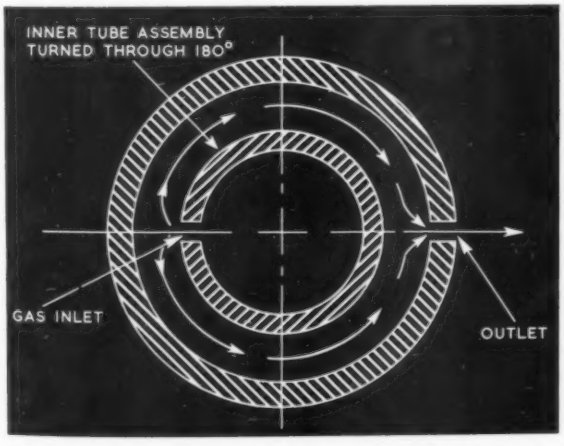


Fig. 1.3. Post-aerated slot type of ladder pilot.

1.8 CHOICE OF DEVICE

Flame-failure devices are fitted to gas-heated appliances to protect against either or both of two types of hazard, namely, danger to persons and risk of financial loss. Taking this latter risk first, money is invested in plant, and in the work which undergoes treatment in that plant. Expensive plant, or plant in which valuable material may be spoiled, can be provided with protective devices of a higher standard than would be warranted by the danger of explosion. Care of such financial risk can usually be left in the hands of the consumer, on being acquainted with the type of equipment available.

With respect to risk of personal injury, the position is somewhat different in that the consumer should be given recommendations, based on experience and special knowledge, as to the type of protective device, if any, which should be fitted. The final choice is again in the hands of

* Biggs, F. C. W. "Ladder Pilots for Central Heating Units", *Gas World*, 1953, **137** (3576), 876.

the consumer, who should, however, fully appreciate the significance of his choice.

The assessment of explosion risk in relation to the installation of industrial gas equipment calls for the exercise of judgment in each case, since no hard and fast rule can be laid down. The primary source of danger is the accumulation in enclosed spaces of mixtures of air and town gas at concentrations within the explosive limits (1 cu. ft of town gas can produce up to 20 cu. ft of explosive mixture). Secondary explosions can be caused by, for example, inflammable vapours or dusts connected with the material being treated, and such possibilities must always be looked for when the fitting of protective devices is under consideration.

The major factors to be considered are gas rate, enclosed volume, and the type of construction adopted. The decision whether to fit a flame-failure device depends on the enclosed volume, having due regard to the design and method of construction coupled with any secondary hazards. This decision having been taken, the type of device to be fitted depends on the gas rate rather than on the enclosed volume, higher gas rates requiring devices of quicker response.

1.9 ASSOCIATED EQUIPMENT

Many flame-failure device installations embody ancillary equipment, such as the electrically-operated valves used with electronic devices, and relay control valves sometimes used with thermoelectric devices. The choice of ancillaries is dealt with later when the installation of the various types of device is discussed, but the point stressed here is that *it is most important that the performance of the installation shall not be reduced to a lower level than that intrinsic to the flame-failure device itself, either by introducing new causes of failure, or by unduly lengthening the time of response*. The resistance to gas flow of all gas-carrying components should comply with the requirements of Table 1.

The fitting of a low-pressure cut-off valve as an ancillary device can ensure that all burner cocks controlled by a flame-failure device must be turned off before re-ignition. It must be emphasised that only the manual weep reset type of low-pressure cut-off valve is suitable for this purpose.

Although a lighting torch is desirable in a manually ignited installation, there is the danger that it might become used as an unprotected pilot, and thus the installation should be designed as far as possible to prevent this being done, i.e., by avoidance of arrangements wherein the lighting torch can be left in a position where it will ignite the main burner.

Ancillary equipment of all kinds is dealt with at greater length in I.G.D.C. Report No. 538/53, D 034, "Ancillary Equipment for the Operation and Control of Gas-heated Plant", to which reference should be made.

Thermal Expansion Devices

2.1 INSTALLATION—GENERAL

The gas industry cannot approve the use of any type of device with an inherent ability to fail to danger. It must also be realised that any device, however satisfactory, can be rendered ineffective, and therefore dangerous, by incorrect installation.

The following installation requirements are general to all types of device:

(a) the gas-carrying component or ancillary which controls the gas supply to the main burner must be placed downstream of the appliance isolation cock, on either side of the governor, and preferably upstream of all other controls;

(b) it is always the responsibility of the person in charge of installing the device to ensure that the protected pilot is located so that it will ignite the gas issuing from the main burner under all circumstances, and will not be subject to excessive variation of ambient temperature or air speed;

(c) after maintenance has been carried out a shut-down test must always be made to ensure that the device is left functioning correctly;

(d) the continued efficiency of all types of device is best ensured by devising and adhering to a routine for closing down the appliance which will test the operation of the flame-failure device. Such a routine, which could with advantage be adopted as the normal closing-down routine, would be to turn the gas off to produce conditions of flame failure. If this procedure is adopted, it is necessary to observe the operation of the device, since if it fails during this test and the gas supply is subsequently restored a dangerous condition would result; and

(e) weep pipes from controls such as relay valves should be terminated in the manner indicated in the following list in which methods are given in order of preference:

(i) It is always preferable, if other considerations permit, to return the weep gas to the main supply. This gives full protection. In many cases this will result in proportional (modulating) temperature control.

(ii) If method (i) is not practicable, weep gas may be discharged into the combustion chamber, close to the pilot burner, always provided that the weep is fully protected by a flame failure device.

(iii) Where the use of certain systems for multiple-burner protection results in the weep being unprotected, and method (i) cannot be adopted, the weep gas should be discharged at some safe place such as a point reasonably high in a lofty building, or outside; this must, of course, be individually determined for each installation.

2.2 BIMETALLIC STRIP AND DISC TYPES

Bimetallic strips are characterised by the need for regular inspection and replacement, and ready access to them for this purpose is essential. The most common cause of failure is fatigue of the bimetallic strip.

Where bimetallic devices are indirectly fitted, the arrangement should ensure that gas cannot reach the main burner until a satisfactory pilot flame is established. A low-pressure cut-off valve is best used, since, unlike a relay valve, it ensures that the operator is not still in the act of lighting the pilot when gas is admited to the main burner.

2.3 UNIMETALLIC ROD TYPE

This is a comparatively new principle and no device employing it has been fully developed in this country to give a satisfactory performance.

2.4 BIMETALLIC ROD TYPE

The susceptibility of these devices to fatigue differs only in degree from that of the bimetallic strip devices.

Rod-type devices, if used, should preferably be fixed with the rod vertical, but if this is not possible the rod should be adequately supported to minimise sagging.

2.5 FLUID EXPANSION TYPE

Installation of this type of device is governed by similar considerations to the installation of thermoelectric devices. Thus the considerations listed in Section 3 apply if "sensitive bulb" is read instead of "thermocouple", and all reference to the press button is ignored. At the moment such devices are not in general use.

2.6 SERVICING

Attention must be given to the following points when servicing these devices:

(a) regular replacement of bimetallic strips and discs; six-monthly intervals are suggested;

(b) dressing of any leather diaphragms which may be employed;

(c) cleaning of orifices, for example, weeps, restrictors and jets;

(d) replacement of worn parts;

(e) examination of the installation to ensure that it is rigidly mounted and that the pilot is properly located with respect both to the main burner and to the sensitive element; and

(f) a shut-down test to ensure the device is left functioning correctly.

Electronic Devices

4.1 INSTALLATION—GENERAL

The gas industry cannot approve the use of any type of device with an inherent ability to fail to danger. It must also be realised that any device, however satisfactory, can be rendered ineffective, and therefore dangerous, by incorrect installation.

The installation requirements are general to all types of device. (See (a) to (e), Section 2.1.)

The wiring to, and fitting of, all electronic flame failure devices must comply with the Electricity (Factories Act) Special Regulations, 1908 and 1944, and the "Regulations for the Electrical Equipment of Buildings", published by the Institution of Electrical Engineers.

4.2 BASIC PRINCIPLES

Flames possess several properties which can be used to provide a signal which can be fed into an electronic circuit. The signal is then amplified to energise either directly, or by means of relays, solenoid valves controlling the flow of gas. In this review these two essential functions will be considered separately, the sensing elements in Section 4.3 and the relay units in Section 4.4.

4.3 SENSING ELEMENTS

4.3.1 TYPES AVAILABLE

Electronic flame-failure devices in this country use sensing elements reacting to thermal radiation or flame conduction. The principles of flame capacity and flame rectification may also be used in the future.

4.3.2 FLAME ELECTRODE SYSTEMS

The presence of ions formed in the course of combustion renders a flame conductive to electricity. A heat-resisting electrode, carried in an insulated holder, is placed so that it is in contact with the flame. An e.m.f. is applied to the electrode and, if a flame is present, the circuit is completed via an earthed burner and, provided the resistance of the flame is within the range for which the circuit is designed, a relay is energised. However, it is possible, in some flame-conductance devices, for a leakage path to provide a resistance within the operating range while there is no flame present. This will give rise to a condition of danger, and such a device fails to satisfy Indispensable Characteristic (b), Section 1.3. In recently developed devices, circuit modifications eliminate this source of danger, and it is only these devices that the gas industry can approve.

4.3.3 PHOTOELECTRIC SENSING

Photoelectric devices depend upon the detection of radiation from a flame, and, in consequence, can be so placed as to avoid contact with the flame or any particularly hot part of the apparatus in which they are used. With the elimination of the necessity to use heat-resisting materials of construction, robust sensing elements can be made at relatively low cost.

Photoelectric sensing devices must be selective to the radiation from the flame itself, and this requirement is not easy to fulfil. It has not proved practicable to devise a system responsive to the intensity or wavelength of the flame radiation, yet unresponsive to that from extraneous sources such as hot brickwork or electric lamps. The only satisfactory circuits respond solely to the fluctuations in radiant intensity associated with all types of flame, but not to the steady component of flame radiation which is so difficult to distinguish from that given by the other sources referred to. With these circuits, it is possible, however, under very unfavourable circumstances, to have the total infra-red radiation of such intensity as to swamp the effect of fluctuation of the infra-red radiation from the flame; the presence of a flame is thus unrevealed and the main gas valve will be closed unnecessarily.

It is not within the scope of this review to consider all the types of photoelectric cell that might be used, but it is pointed out that all cells must be inspected regularly and replaced if necessary, in the same manner as thermionic valves. A deposit obscuring the lens of such a device cannot but cause failure to safety.

4.4 RELAY UNITS

A relay unit is, for the present purpose, defined as having the separate functions of:

(a) rectifying the mains current;

(b) amplifying the usually very small current flowing in the sensing circuit; and

(c) using the amplified current to actuate the control switches or to operate a solenoid gas valve directly.

The multiple switches used can be operated by solenoid or motor-driven cam. The latter method is probably the more flexible. Both switchgear and the associated circuits in relay units are available in varying complexity to meet a range of requirements, which includes safe starting and control of multiple burners.

4.5 CONTROL SYSTEMS AVAILABLE

The more complex an installation, the more complex the device required to protect it. Systems are now available to deal with most installations encountered. Examples of such systems are given here in order of increasing complexity:

(a) *System with spark ignition and protected pilot.* This system is shown diagrammatically in Fig. 4.1. The sensing element responds to both the pilot and the main gas flames. The relay unit ensures that only after the pilot flame has been established will the main gas valve open. Upon lighting up, the air fan (if fitted) should be allowed to run for some time before ignition is attempted, in order to purge the combustion chamber. After cocks in the pilot and main gas supplies have been opened, the starting button on the relay unit is pressed, thus bringing the spark ignition into play and opening the pilot gas valve. Once the pilot flame is established, the main gas valve opens automatically and the starting button may be released. Upon flame failure, both pilot and main gas valves are closed.

Simpler forms of this system *which are not recommended* use manual ignition instead of spark ignition. A lighting torch will then be the means of ignition, and it is because it may then be possible for this torch to become an unprotected pilot that this system is not recommended.

(b) *Addition of air flow switch.* Where air fans are fitted, an air flow switch may be incorporated into the control system, so that failure of air flow shuts off gas

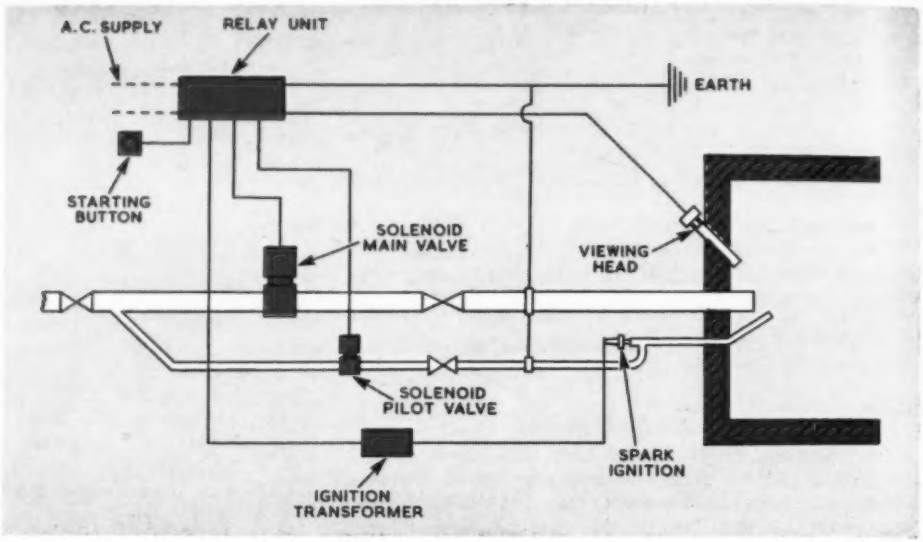


Fig. 4.1. System with spark ignition and protected pilot.

to both main and pilot burners. Such an arrangement will also ensure that the burner system cannot be started up unless the fan is running.

Air flow failure devices are due to be dealt with in a later publication. It may be noted here that those devices which are actuated by air flow are *always preferable* to those which are sensitive to air pressure or suction.

(c) *Addition of alarm.* Audible or visible alarms may be incorporated to indicate flame failure.

(d) *Addition of purge timers.* It has already been noted that where air fans are fitted it is desirable to allow purging of the combustion chamber before ignition is attempted. Arrangements can be made for a predetermined purging period to elapse before ignition of the pilot flame. Such provision is commonly made by use of a thermal delay switch.

(e) *More complex devices.* Devices now entering the market provide for further flexibility in the control-sequence, it being possible to provide for a more complex lighting-up system or for a desired closing down procedure. Process timing can also be incorporated in such systems. Great flexibility in design is possible, and consultation with the manufacturers of such devices will reveal whether or not any plant can be controlled by the devices available. Finally, the number of schemes possible is so great that it is not within the scope of this review to cover them.

(f) *Protection of multi-burner installations.* Devices have now been developed which afford protection to multi-burner installations. The switchgear is similar to that for the devices used to protect single burners, but each burner of the multi-burner installation is fitted with a sensing element, and these, in turn, feed separate amplifying circuits. When flame failure occurs at any one burner the gas is immediately shut off from all burners. A further possibility is the use of electronic flame-failure devices to replace thermoelectric devices in installations of the type described in Section 3.3.1.

4.6 INSTALLATION OF COMPONENTS

Electronic devices, perhaps more than any other, resolve into a series of components, some essential and some optional, and there is thus scope for variation and for error in the choice made and in the assembly of the installation. Requirements for the proper installation of the commonly used components are set out below.

4.6.1 PILOT BURNER

The practice of fitting an electronic flame-failure device without incorporating a pilot burner is strongly to be discouraged for the following reasons:

(a) the main burner will probably pass too much gas to be lit safely with a hand torch or electric spark; and

(b) with automatic temperature control, the main burner may fluctuate over too wide a range to result in stable operation of the flame-failure device.

The following conditions should be observed with respect to the installation of the pilot burner:

(a) it should preferably be controlled by a direct-acting solenoid valve connected so that it opens when the start button is pressed. The main gas valve must always be arranged so that it does not open until the pilot flame has been established;

(b) it should be permanently and rigidly fixed so as to ignite the main burner under the lowest probable pressure conditions;

(c) where there is any likelihood of sooting, it should be of the aerated flame type.

(d) when a flame electrode is used, if the pilot burner is fitted with a tip or tips made from steatite or other electrically non-conducting material, a conducting path must be provided between the pilot flame and the earthed pilot-burner supply by welding to the latter a conductor, preferably of the same material as the electrode; and

(e) if the pilot tip is metallic, it must be realised that a streamlined flame may not make electrical contact with the tip. Streamlined pilot flames should therefore be avoided, and, if necessary, an earthed electrode should be provided.

4.6.2 FLAME ELECTRODE

(a) the electrode should be arranged so that it is only that part of the pilot flame that will ignite the main burner. Only thus can it be ensured that a pilot flame which will energise the relay unit will also ignite the main flame;

(b) the insulated housing of the electrode should be rigidly fixed to the appliance;

(c) the electrode should be clear of brickwork or any metal structure and, whenever possible, it should be installed vertically downward, or at least obliquely downward. This reduces the tendency to sag out of position at high temperatures and also reduces the accumu-

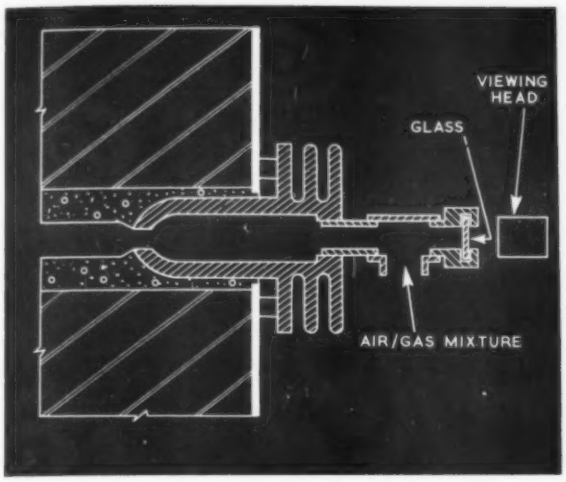


Fig. 4.2. Flame detected through burner ports.

lation of foreign matter on the electrode insulator; and

(d) it is essential that the electrode insulator be kept clean, since it must maintain a resistance to surface leakage many times higher than the impedance of the flame. which itself may be as high as 250 megohms. It is desirable that access to the electrode insulator be easy, as in some cases cleaning must be carried out regularly.

4.6.3 VIEWING HEAD

(a) the viewing head must be so aligned that it detects only that part of the pilot flame that will ignite the main burner. Only thus can it be ensured that a pilot flame which will energise the relay unit will also ignite the main flame;

(b) the insulated housing of the viewing head must be rigidly fixed to the appliance. *Special attention to this point is necessary;*

(c) care must be taken to prevent overheating of the viewing head. Apart from the possibility of damage, it must be remembered that the sensitivity of the photocell diminishes with increase in temperature. A useful means of achieving low cell temperatures is the interposition of a glass window;

(d) easy access to the outer surfaces of the lens and of the window is necessary for cleaning; and

(e) where convenient, the flame may be detected through the burner ports. An example of this practice is outlined in Fig. 4.2.

4.6.4 AMPLIFIER AND RELAY ASSEMBLY

(a) this should be mounted on a wall or panel in a position reasonably free from vibration and from excessive heat; and

(b) it should be as near as possible to the appliance which is to be protected. (See, however, 4.6.5 below for special considerations applying to manual ignition installations.)

4.6.5 START BUTTONS—MANUAL IGNITION

It is recommended that when manual ignition (which should be by gas torch) is to be used, two start buttons be employed. The first, a pilot start button, should be located so that one operator can conveniently ignite the pilot flame while holding in the button. The second button, controlling the main gas valve, should be situated close to the relay unit (it is sometimes incorporated in the relay unit) and also out of reach of the operator while he is pressing the pilot start button.

4.6.6 SPARK IGNITION

(a) the high-tension transformer must be fitted as near as possible to the burner, and under no circumstances adjacent to the control panel;

(b) the high-tension lead must be in a separately earthed conduit;

(c) the spark plug must be securely mounted in a suitable position in relation to the pilot burner; and

(d) if a spark electrode is used, this must be rigidly mounted so that the preset spark-gap is maintained, and it should preferably be installed vertically downward. It should be clear of all refractories or metal likely to cause a short circuit, and should be as short as possible in order that it may itself have maximum rigidity.

4.6.7 MAIN GAS VALVE

The same considerations apply when selecting ancillaries for use with electronic flame-failure devices as apply to switch-type thermoelectric devices, namely that rapid closing on flame failure has to be associated with slow opening on ignition and on operation of the automatic control. Where manual ignition is adopted, warnings should be issued instructing the operator to ensure that the main-burner control valve is in the off position before he attempts to light the pilot burner.

4.6.8 ELECTRICAL CONNECTIONS

(a) all electrical circuits from the mains to the amplifier and thence to the control valves, and the screened cable (if used) for the electrode, should be run in separate conduits.

(b) the screened cable (if used) to the electrode should be earthed at the control panel end only;

(c) this type of device should be tested frequently by the use of a suitable closing-down routine; it is therefore not desirable that an electrical "stop" button be provided;

(d) the installation must comply with the Electricity (Factories Act) Special Regulations, 1908 and 1944, and the "Regulations for the Electrical Equipment of Buildings", published by the Institution of Electrical Engineers;

(e) where 230-volt components are employed in conjunction with a 440-volt supply it is good practice to connect:

(i) Across phase and neutral of a four-wire system.

(ii) Across two phases of a three-wire system in conjunction with a step-down earthed transformer.

The use of a resistor in place of a transformer to break down the voltage from a 440-volt supply *is deprecated.*

4.7 SERVICING

Attention must be given to the following points when servicing electronic devices:

(a) the optical system of photocells must be subject to regular cleaning;

(b) the location and rigidity of flame electrodes and photocells must be checked;

(c) the insulation of all electrical connections, particularly those to electrodes, and the high-tension leads for spark ignition must be examined for soundness;

(d) the spark gap in all spark electrodes and the rigidity of the electrodes themselves must be checked;

(e) the performance of the pilot burner and of all ancillaries such as solenoid valves, warning lights, bells, etc., must be checked; and

(f) a shut-down test should be carried out to ensure that the device is left functioning correctly. In the case of multi-burner installations, a separate shut-down test should be carried out on each burner.

EXTRACTION CALCULATIONS

A Comparison of Graphical and Analytical Methods

by Prof. D. S. DAVIS

For calculations of a typical multiple-contact extraction process, two graphical methods, which employ different scales for solute concentration, are compared with the rigorous analytical method

CALCULATIONS of extraction processes are often performed graphically because of the excessive amount of time required for analytical or algebraic solutions of the various material balances. Since graphical computation is subject to some uncertainty, for the sake of accuracy a good grade of cross-section paper and sharp 4-H pencils should be used for the construction, and expanded-scale plotting should be employed as far as space permits.

Graphical and analytical calculations were made for the following process. Three thousand pounds of a solution containing 2% solute and 98% solvent (S_o) are used per equilibrium contact in extracting solute from 12,000 lb. of a feed containing 10% solvent, 50% inert solids and 40% solute (R_f). A saturated solution at operating temperatures contains 40% solute; drainage characteristics are such that 2 lb. of inert solid retain 1 lb. of solution.

How many equilibrium contacts are needed to reduce the solute in the solids to 6% and what is the percentage of solute in the solids after five equilibrium contacts?

Analytical and Graphical Methods

In Fig. 1, part of a right triangle is used to represent the system. R_f, which has co-ordinates of (10, 40), corresponds to the feed mixture; S_o, with co-ordinates of (98, 2), represents the extracting solution; a point with co-ordinates of (60, 40) corresponds to the composition of the extracts E_o, E_1 and E_2. Note that the first and second extracts are saturated solution. The equations of the basic lines of the diagram are:

Solution line (hypotenuse) ... $y = 100 - x$

Drained solids line, xx ... ... $y = \frac{100}{3} - x$

Saturation line ... ... $y = \frac{2}{3}x$

where x = percentage of solvent; and
y = percentage of solute.

Draw the dotted line R_fS_o. The x-co-ordinate of J_1, the mixture of R_f and S_o, is $10 + \frac{3000}{3000+12,000}(98 - 10) = 27.6$; the y-co-ordinate of J_1 is $40 - \frac{3000}{3000 + 12,000}(40 - 2) = 32.4$. Note that the saturation line meets the drained solids line xx at the vertical line for 20% solvent. Draw

Prof. Davis, *who is known as the "nomogram king", is the author of "Chemical Engineering Nomographs" (McGraw-Hill Book Co. Inc., New York and London, 1944). At present he is head of the Department of Pulp and Paper Technology at the University of Alabama.*

TABLE 1

	R_3	R_4	R_5	E_3	E_4	E_5
x	25.3992	29.0335	30.8503	76.1977	87.1006	92.5509
y	7.9341	4.2998	2.4830	23.8023	12.8994	7.4491

TABLE 2

Contact No.	Extract, lb.	Frac. solute	Solute, lb.	Extract lb.	Frac. solute	Solute, lb.	Extract, lb.	Frac. solute	Solute, lb.
1	2850.1	0.4000	1140.0	2820	0.400	1128	2780	0.400	1112
2	5853.4	0.4000	2341.4	5900	0.400	2360	5750	0.400	2300
3	3299.6	0.2380	785.4	3320	0.235	780	3300	0.235	776
4	2998.3	0.1290	386.8	2990	0.126	377	3030	0.130	394
5	2975.0	0.0745	221.6	2950	0.073	214	2970	0.071	211
	17,976.4		4875.2	17,980		4859	17,830		4793

	Analytical Solution	Graphical Expanded scale	Solutions Non-expanded scale
Cumulative percentage solute	$\frac{4875.2}{17,976.4}(100) = 27.12$	$\frac{4859}{17,980}(100) = 27.00$	$\frac{4793}{17,830}(100) = 26.88$
Percentage solute in solids after four contacts ...	6.06	5.9	5.8
Percentage solute in solids after five contacts ...	3.59	3.5	3.5

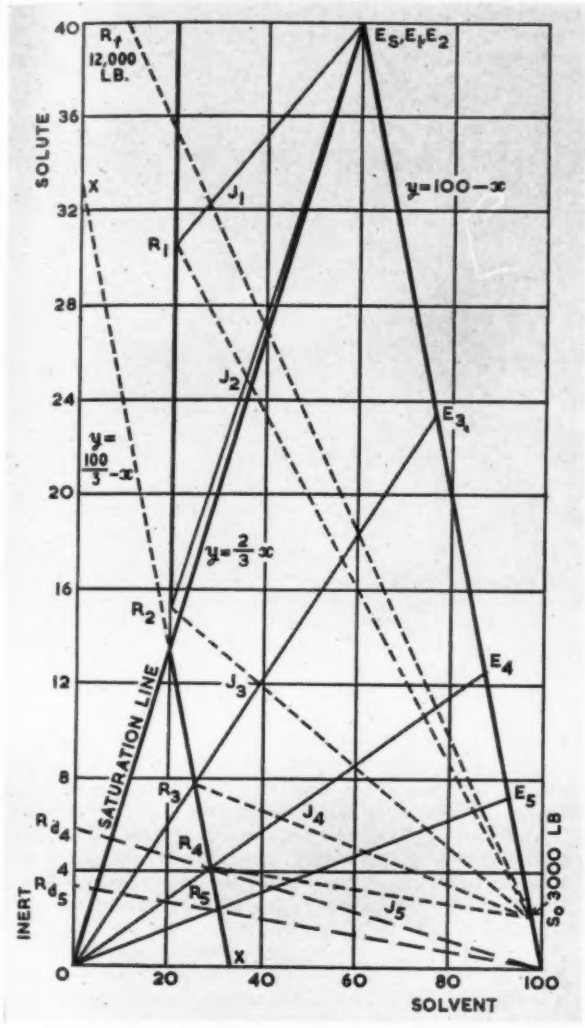


Fig. 1. Graphical and analytical solution to a simple multiple-contact extraction problem.

the light solid line E_1J_1 to intersect the vertical line for 20% solvent at the point R_1. The equation of E_1J_1, found by subsituting the co-ordinates of E_1 and J_1 into the equation $y = a + b\,x$, is $y = 25.9260 + \frac{19}{81}x$. The weights of residual material and extract are obtained from the ratio of J_1E_1 to R_1E_1. The x-co-ordinate of R_1 is 20 and the y-co-ordinate is $25.9260 + \frac{19}{81}(20) = 30.6160$. That of $\overline{J_1E_1}^2 = (60 - 27)^2 + (40 - 32)^2$, from which $J_1E_1 = 33.2795$; $\overline{R_1E_1}^2 = (60 - 20)^2 + (40 - 30.6160)^2$, from which $R_1E_1 = 41.0860$. The weight of $R_1 = \frac{J_1E_1}{R_1E_1}(15{,}000) = \frac{33.2795}{41.0860}(15{,}000) =$ 12,149.9 lb. and the weight of E_1 is 15,000 — 12,149.9 or 2850.1 lb.

Repetition of this calculation again with the x-co-ordinates of $R_2 = 20$ yields the weights of R_2 and E_2 as 9296.7 and 5853.4 lb. respectively. Simultaneous solution of the equations for the lines OJ_3, OJ_4 and OJ_5 with $y = \frac{100}{3} - x$, the equation for the drained solids line, xx, yields the co-ordinates of the points R_3, R_4 and R_5. Similarly, simultaneous solution of the equations for the lines OJ_3, OJ_4 and OJ_5 with $y = 100 - x$, the equation of the solution line, yields the co-ordinates of the points E_3, E_4 and E_5. These values are given in Table 1.

The percentage of solute in the solids after four contacts, R_{d4}, is found from

$$\frac{R_{d4}}{4.2998} = \frac{100}{100 - 29.0335}$$

to be 6.0% which indicates that four contacts are not sufficient to achieve the desired 6%. After five equilibrium contacts, the percentage of solute in the solids, R_{d5} is given by $\frac{2.4830}{100 - 30.8503}(100) = 3.59$.

A graphical solution employing an expanded scale is shown in Fig. 1. In full-size form, 1 in. corresponds to 20% along the horizontal percentage solvent scale x, whereas 1 in. corresponds to 4% along the vertical solute scale y. In another graphical solution, not shown here, 1 in. represented 20% on both the horizontal and vertical scales. For both graphical solutions, a good grade of cross-section paper (20 lines to the inch) was chosen and line segments were measured with an engine-divided scale graduated in millimetres.

Comparison of Results

Table 2 presents a comparison of results obtained by means of the analytical method and the two graphical methods. Both graphical solutions lead to an approximate answer which showed that four equilibrium contacts are sufficient to achieve 6% solute in the solids; the analytical solution shows that four contacts only can reduce the percentage to 6.06. Both graphical solutions show that five equilibrium contacts should reduce the percentage of solute in the solids to 3.5; the analytical solution shows that only 3.59% can be attained. The percentage solute in the combined extracts from the five contacts is 27 when the expanded-scale graphical solution of Fig. 1 is used, and 26.88 when the horizontal and vertical scales are the same. The true value, from the analytical solution, is 27.12%.

As shown, this extraction calculation can be handled graphically or analytically. Reasonable agreement between the two methods can be attained when expanded scales are used. The graphical method is, of course, more rapid than the analytical procedure.

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Fresh Water from the Sea

THE CROWN AGENTS for Overseas Governments and Administrations have placed an order with G. & J. Weir Ltd., the Glasgow engineers, for sea-water evaporating and distilling plant for the Clifton Pier power station of the Bahamas Electricity Corporation. The installation embodies two independent units, each of which produces more than half a million gallons of fresh water daily for domestic use and a small quantity for supplying the power station boilers with de-aerated feed water. This order, worth more than £500,000, was obtained in international competition through the consultants Preece, Rider & Cardew, London, and follows closely on recent export orders for installations supplied by Weirs to Kuwait (Persian Gulf), Curaçao and Aruba (Netherlands Antilles) and Lobitos (Peru). The total value of these export orders runs into millions of pounds.

A feature of the equipment for the Bahamas order is that it will be made largely of "Colclad" stainless steel in an entirely new design, and fabricated at the site.

AMMONIUM NITRATE AND RELATED FERTILISERS

This article reviews the earlier methods of ammonium nitrate manufacture and discusses the modern continuous process based upon the neutralisation of ammonia and nitric acid

by L. S. GREENSLADE, B.Sc., A.M.I.Chem.E.

AMMONIUM nitrate is difficult to detonate, but can be made to act as a vigorous explosive; as a fertiliser material it contains nitrogen in both the common forms in which nitrogen can be applied to the land. The first extensive production of ammonium nitrate was in Germany during the First World War. Afterwards intensive efforts were made to maintain their producing plants in operation by selling the ammonium nitrate as a fertiliser.

For this purpose, the material left much to be desired. It is extremely hygroscopic and in storage tends to form a rock-like cake which is very difficult to break up. As far as distribution went, this could be got over by the use of air-tight cans, but bulk storage still presented a difficulty. At Leuna, Germany, this was met by the marketing of a sulphate-nitrate mixture which was claimed to be completely inert to detonation; the vast explosion at Leuna in 1923 proved otherwise.

Intensive research in a number of countries, notably the United States, developed two separate approaches by means of which ammonium nitrate can now be safely handled and sold as a fertiliser. The first method is to prepare the material in the form of granules which are then coated with a water-repellent wax-resin mixture, mixed with a conditioning agent such as kieselguhr or kaolin. A certain fire hazard still exists with this method, and it is necessary to prevent the introduction of organic materials and metallic powders, and to burn immediately bags in which it has been contained. The second way of preparing ammonium nitrate for fertiliser use is to mix it with chalk or limestone to form a product which is inert and stable in storage.

The advantages of the dilution method are, however, not only found on the technical side. Many soils are sensitive to the sulphate ion, but will tolerate Nitrochalk, Nitrolimestone, Kalkammonsalpeter, or any of the other various trade names which the material has throughout the world. A further advantage is that the material provides in one application quick-acting nitrate together with ammonia which can be absorbed in the soil and provide a residue of nitrogen which can be made available to the plants over a long period. Finally, since all nitrogenous fertilisers are ultimately converted to nitrate in the soil, and are then washed out as calcium nitrate, their application must generate soil acidity; the mixing of lime with the fertiliser goes far towards neutralising this effect.

Ammonia nitrate as prills (i.e., coated granules), with lime and as nitrogen solutions, for example a solution of ammonium nitrate which also contains dissolved ammonia, now comprises some 60% of the total fertiliser nitrogen now used in America. This compares with a figure of some 10% in 1940, and the total American consumption is now in excess of 600,000 ton/year of nitrogen.

Europe, whose main source of fertiliser nitrogen has been ammonium sulphate, may follow the American trend.

Ammonium Nitrate Manufacture

Solid ammonium nitrate is available in two forms, either crystalline or as prills. Prilled ammonium nitrate consists of spherical particles, which are obtained by spraying a concentrated aqueous solution, or the molten anhydrous compound into a tower, up which air is blown. Plants for ammonium nitrate are usually so arranged that solid product or ammonia solutions can be supplied according to demand. Originally, the most usual method for the manufacture of ammonium nitrate was by the double decomposition of ammonium sulphate and sodium nitrate, but as the cost of synthesis of ammonia and of nitric acid has been reduced, the direct neutralisation method has become the only one of importance.

An advantage of ammonium nitrate as a source of nitrogen is that it contains both nitrate and ammoniacal nitrogen, thus supplying both short- and long-term nitrogen nutrition. In addition, it does not introduce sulphate which is harmful in some soils, and the nitrogen content (33 to 35% depending on the amount of conditioning agents added) is higher than in other nitrogenous fertilisers.

As has been stated above, the double decomposition reaction is no longer used for the production of ammonium nitrate; the entire production is by the direct neutralisation of nitric acid. Further, where in the past ammoniacal solutions from gas-works liquors have been used, the main source of ammonia is now synthetic ammonia, which is taken to the plant either as liquid or gas. The nitric acid is usually in the form of a 55 to 60% solution in water.

Mr. Greenslade *was educated at Highgate School and Battersea Polytechnic where he graduated in chemistry in 1950, taking the Battersea Diploma in Chemical Engineering in the following year. After three and a half years with the Ministry of Supply at the E.R.D.E., Waltham Abbey, he joined Constructors-John Brown Ltd., and is now project engineer for the nitrogen-based fertiliser plant at present being erected for Fisons at Shellhaven.*

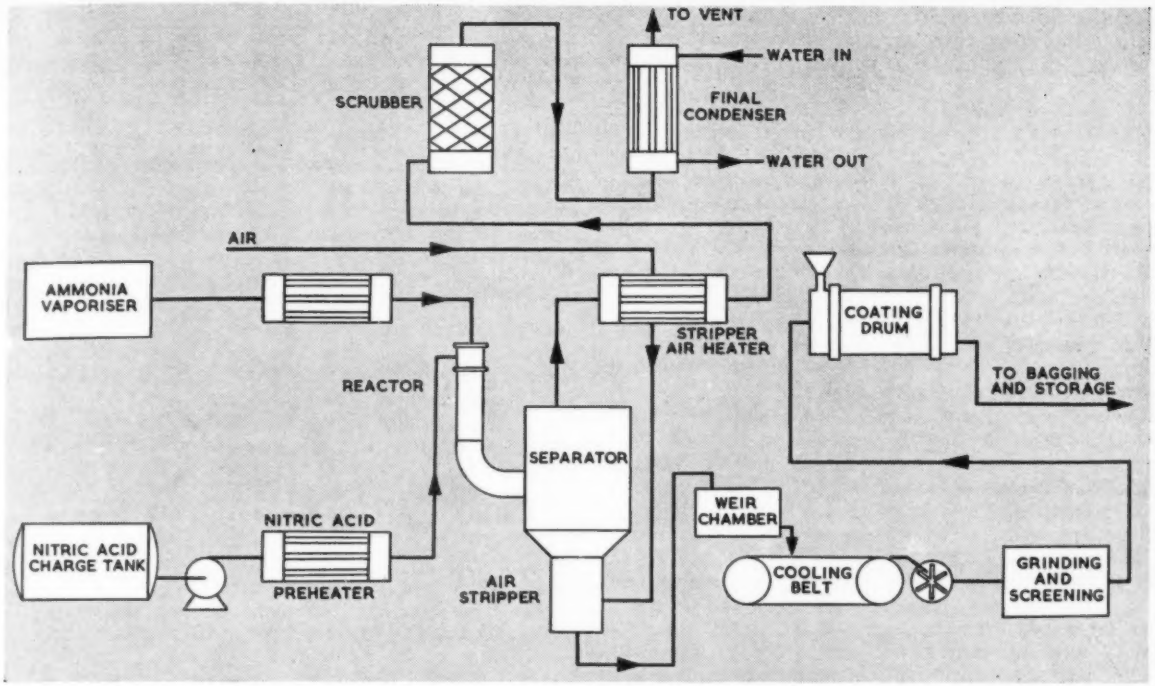

Fig. 1. Diagram of a solid ammonium nitrate plant with Stengel reactor. This process is representative of the latest neutralisation methods and has the advantage over other processes of lower power and steam consumption.

The heat of neutralisation of nitric acid by ammonia is very large, being some 12 K.cal/mole, and this has to be removed during the reaction. In addition, both the reactants are very volatile and care must be taken to prevent a lowering of the yield by loss of the reactants.

The earliest neutralisation process was a batch process in which aqueous nitric acid and gaseous or liquid ammonia are added continuously to an acidified heel of ammonium nitrate solution. The heat of reaction is removed, and the solution maintained slightly below its boiling point. As nitric acid is the less volatile of the reactants, the solution is maintained slightly acid. When sufficient solution has been obtained, it is evaporated by heating in large open pans to a concentration of about 95% ammonium nitrate. After this concentration step, the heat for which is supplied by steam, the final traces of water are removed in a graining kettle, the size of the particles being controlled by the rate of stirring and control of the temperature.

This process is uneconomic, as the heat of reaction is not utilised for the evaporation. Several continuous processes have been developed to do this, in which the nitric acid and gaseous ammonia are preheated, and the reaction carried out under pressure, the heat of reaction being used to flash off the water present in the nitric acid. This steam is then used to vaporise and preheat the ammonia. In this way, ammonium nitrate solutions of 95% strength and greater can be obtained directly from the reactor.

The method of carrying out this continuous reaction has been made the subject of several patents,[2, 3, 4] the object of them all being to use the reaction heat for evaporation.

A typical continuous reactor would be a packed tubular column constructed of stainless steel. The reactants are fed at controlled rates, and the proportions are controlled by the *pH* of the product. From the reactor the reactants flow into a cyclone-type separator where the steam and molten ammonium nitrate are separated. This vessel is also constructed of stainless steel, as molten ammonium nitrate is very corrosive. The steam from the separator can be used to vaporise the ammonia and is thus condensed and discharged. In this way, solutions of approximately 90% ammonium nitrate are obtained, which is sufficient concentration for ammonia solutions. If this is the required product, then it can be pumped to heated storage tanks, where the additional ammonia can be dissolved. The ammonia is usually metered into the solution while it is being circulated through a mixing chamber.

However, if the product is required as prills or as crystalline ammonium nitrate, then the concentration must be increased before crystallisation. The method by which this is carried out depends on the process adopted.[1, 5, 6, 7] In some processes the heated solution is finally concentrated in an evaporator, which is also constructed of stainless steel. This increases the concentration to upwards of 95%. If a prilled product is desired then the solution is sprayed into a tower 100 to 150 ft high, up which a current of air is passed. This cools the product which crystallises into spherical particles. The size and density of these particles can be varied by the method of spraying, the air velocity up the tower and the concentration of the solution. The prilled product is continuously discharged from the bottom of the tower and passed to rotary driers, the drying agent being hot air. It is then cooled and treated with a conditioning agent (for example, clay) before being bagged for storage.

Another process[8] developed by the Chemical Solvent Corporation in America, and licensed to the Chemical & Industrial Corporation, avoids the use of an evaporator after the reactor by fitting an air-blown stripper to the bottom of the reactor separator. The air passes through the stripper and separator, removing the last traces of water and producing an essentially anhydrous melt. From the top of the separator the air is cooled by heat exchange

with the incoming air, and then scrubbed free of any unreacted ammonia or ammonium nitrate which has been carried over. The air passes through another final contact condenser and is then vented to atmosphere.

If a prilled product is required, the anhydrous molten ammonium nitrate is sprayed into a short air-blown tower and a high-density product produced. The air velocity in the tower is higher than in conventional processes. The product drawn from the bottom of the tower does not need further drying and has only to be passed to a rotary cooler before conditioning and bagging. The production of essentially anhydrous ammonium nitrate in the reactor enables a much smaller tower to be used for the prilling than is usual, and eliminates the need for rotary driers after the tower. The prilling towers are constructed of aluminium sheet on a steel frame, and the rest of the plant constructed of stainless steel.

If a crystalline and not a prilled product is required, both the processes described above can be used. For a crystalline product, the highly concentrated or anhydrous melt from the evaporator or stripper is passed to a weir box, from where it flows on to a series of cooling belts. These are water-cooled stainless-steel belts and form a thin sheet of crystalline ammonium nitrate. This is flaked off by breakers, and is then ground and screened. The undersize from the screen is returned to the process by dissolving it in the nitric acid feed. The sized crystals are then coated and bagged.

For a typical plant using an evaporator, and utilising the reaction heat to preheat the ammonia, some 1600 lb. of steam/ton of ammonium nitrate are required. In addition to this, 36 kWh of power and 1500 gal. of cooling water are required for each ton of product. The Stengel process (see Fig. 1), by avoiding the use of the evaporator, decreases the steam and power usage to 1200 lb. and 25 kWh/ton respectively. The cooling water requirements are somewhat higher, however, being some 2500 gal./ton.

Nitro-chalk Manufacture

For some soils the acidity introduced with ammonium nitrate is harmful, and to overcome this ammonium nitrate is mixed with ground limestone or precipitated chalk to give nitro-chalk. This compound is marketed under various trade names, and usually contains approximately one-third limestone, reducing the nitrogen content to 20%. In addition to preventing acidity of the soil due to the ammonium nitrate, the addition of the limestone is an advantage in itself with some soils. Nitro-chalk finds its main use as a nitrogen side dressing, but some is used in the manufacture of mixed fertilisers.

Nitro-chalk is a mechanical mixture and not a compound, and to ensure an intimate mixture the finely-ground calcium carbonate is introduced during the manufacture of the ammonium nitrate. The concentrated ammonium nitrate solution leaving the separator or evaporator passes to a mixing vessel where the finely-ground chalk is introduced with agitation. The slurry of chalk in molten ammonium nitrate then passes to the prilling tower, and from there through the drying (if required), cooling, conditioning and bagging stages.

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Foundations For Plant

Papers on foundation design and a foundation failure under plant formed part of the programme of the recent Fourth International Conference of the International Society of Soil Mechanics and Foundation Engineering. Summaries of these two papers are given below

Foundation Failure of an Oil Tank in Fredrikstad, Norway

by L. Bjerrum and A. Överland

IN 1952 an oil tank in South-east Norway tilted during the test filling due to a foundation failure. In general, the tanks storing whale oil in a tank park had been constructed using a special technique. This was developed for building on soft, marine, silty clay. The plates were welded from a floating platform inside the tank and, as the height of the tank increased the platform was continually raised by pumping water into the tank. In this way a certain increase in the strength of the clay was obtained due to consolidation during the construction period. In spite of large settlements of 50 to 100 cm, no failure has occurred among the great number of tanks constructed in this way. However, a sudden increase in the delivery of whale oil necessitated the rapid construction of a new tank which was erected without simultaneously and gradually filling with water. The diameter was 25 m and capacity 6000 cu. m. It was founded on a 35-cm-thick gravel layer covered with a 15-cm-thick concrete slab connected to a ring-form outer wall. The weight empty was 550 tons. In a test loading 5000 cu. m of water was pumped into the tank in the course of 35 hours, and a few hours later failure occurred. The total weight was then 5500 tons and the load 11.2 tons/sq. m. After the failure the tank was stepwise filled with water and time allowed for consolidation, and for a further two years it has been used to full capacity. Later field investigations showed that the minimum values of the shear strengths of the clay under the western part of the tank was 2.7 tons/sq. m, while that under the east part was only 1.7. The failure had thus been due to a local failure of the soft clay which resulted in the tank tilting towards the east, and a heave in the ground to the east of the tank.

Foundation Raft for the First Atomic Reactor at Marcoule

by R. L'Herminier, M. Bachelier and F. Soeiro

THE FOUNDATION for an atomic pile is subject to a severe limitation on the allowable differential settlements which must not exceed $\frac{1}{4}$ to $\frac{1}{2}$ mm/m of foundation. The first reactor of the Atomic Centre at Marcoule has been built on the coast on a monolithic rectangular raft 28.76 m × 36 m and of mean thickness 3.80 m. Its geometric centre almost coincides with the centre of gravity of the applied loads. The total load of about 30,000 tons is transmitted to the raft in a non-uniform manner, 80% being concentrated in the central zone. The mean pressure at the interface between the earth and the raft is about 2.94 kg/sq. cm. The design of the raft was mainly determined by the distribution of the contact pressure. Three assumptions were considered: elastic soil, uniform reaction and sinusoidal reaction. Measurements carried out with vibrating wire gauges set inside the raft clearly show the development of the soil reactions between the elastic distribution and the uniform distribution. It therefore follows that the raft foundation must be designed to resist the forces developed by the elastic and uniform soil reactions, the sinusoidal reaction being in this case too conservative. In addition, the calculated settlements were about 25% higher than those actually observed.

Conference proceedings publisned by Butterworths (2 vols., 7 gns.). A third volume will appear shortly.

RUSSIAN ARTICLES ON CHEMICAL ENGINEERING (2)

A select list of articles on chemical engineering or allied subjects which have appeared in the Russian literature during the past two years is presented below. It is intended to publish further lists from time to time, depending upon the number of articles on these subjects appearing in the Russian literature.

General Description of Subject Matter	Title of Article (Free Translation)	Authors	Journal
Flow of fluids and related subjects.	Investigation of frictional resistance and temperature recovery coefficient for the flow of a gas through a circular tube at high subsonic velocities.	B. S. Petukhov, A. S. Sukomel and V. S. Protopopov.	Teploenergetika (Heat Energy), 1957, No. 3, p. 31.
Flow of fluids and related subjects.	Determination of optimum ratio of rates of flow in contraflow air-heaters of gas-turbine plants.	L. G. Gel'fenbein.	Teploenergetika (Heat Energy), 1956, No. 11, p. 51.
Flow of fluids and related subjects.	Measurement of dust flow in a dust-laden stream.	P. A. Antikain.	Teploenergetika (Heat Energy), 1956, No. 12, p. 35.
Flow of fluids and related subjects.	The equalising effect of a system of grids arranged in series.	I. E. Idel'chik.	Teploenergetika (Heat Energy), 1956, No. 3, p. 34.
Materials of construction, protection, against corrosion.	The struggle against corrosion in soda production.	A. S. Gaivoronskii.	Khimicheskaya Promyshlennost (Chemical Industry), 1957, No. 1, p. 50.
Materials of construction, protection, against corrosion.	Corrosion of chemical apparatus by aqueous solutions of monoethanolamine.	M. L. Pytkovskii.	Khimicheskaya Promyshlennost (Chemical Industry), 1956, No. 3, p. 153.
Methods of separating solids from fluids.	Effect of the properties of dust on its removal from gases by the foam method.	M. E. Pozin, E. P. Mukhlenov and V. Ya. Demshin.	Zhurnal Prikladnoi Khimii (Journal of Applied Chemistry), 1955, Vol. 28, No. 8, p. 841.
Methods of separating solids from fluids	The velocity of free fall of particles in a liquid medium.	V. A. Olevskii.	Zhurnal Prikladnoi Khimii (Journal of Applied Chemistry), 1955, Vol. 28, No. 8, p. 849.
Methods of separating solids from fluids.	Analysis of the process of dust collecting in foam apparatus.	M. E. Pozin, E. P. Mukhlenov and V. Ya Demshin.	Zhurnal Prikladnoi Khimii (Journal of Applied Chemistry), 1955, Vol. 28, No. 10, p. 1116.
Methods of separating solids from fluids.	Investigation of the operation of a multi-stage foam scrubber.	M. E. Pozin, I. P. Mukhlenov and V. Ya Demshin.	Zhurnal Prikladnoi Khimii (Journal of Applied Chemistry), 1955, Vol. 28, No. 11, p. 1231.
Methods of separating solids from fluids.	A rational scheme for connection of vacuum pumps and RMK air blowers for filtration of flotation concentrates.	K. D. Voronov and V. A. Butovetskii.	Koks I Khimiya (Coal and Chemistry), 1957, No. 2, p. 58.
Methods of separating solids from fluids.	Air classification of finely ground materials.	A. M. Polotskii.	Khimicheskaya Nauka I Promyshlennost (Chemical Science and Industry), 1956, No. 2, p. 199.
Methods of separating solids from fluids.	Hydrocyclones, their construction and design.	S. Z. Kagan.	Khimicheskaya Promyshlennost (Chemical Industry), 1956, No. 6, p. 347.
Mechanical design of equipment.	Present constructions of high-pressure compressors.	V. A. Rymyantsev.	Khimicheskaya Nauka I Promyshlennost (Chemical Science and Industry), 1956, Vol. 1, No. 6, p. 688.
Mechanical design of equipment.	High-pressure apparatus in the nitrogen industry.	K. V. Mikhailov.	Khimicheskaya Nauka I Promyshlennost (Chemical Science and Industry), 1956, Vol. 1, No. 6, p. 692.
Mechanical design of equipment.	Improvement of pulp trap-design.	P. I. Chaikovskii.	Sakharnaya Promyshlennost (Sugar Industry), 1956, No. 9, p. 58.
Mechanical design of equipment.	Standardisation of column equipment for coke by-product works.	F. N. Shakhov and A. M. Shuer.	Koks I Khimiya (Coal and Chemistry), 1957, No. 5, p. 32.
Mechanical design of equipment.	On the production of railway tankers from AMTs (aluminium-manganese) alloy.	I. B. Dikenshtein.	Khimicheskaya Promyshlennost (Chemical Industry), 1956, No. 2, p. 106.
Mechanical design of equipment.	On designing bimetallic cylindrical shells for stability.	E. I. Grigolyuk.	Inzhenernyi Sbornik (Engineering Symposium), 1956, Vol. 23, p. 28.
Mechanical design of equipment.	Stability of a cylindrical shell with transverse stiffening under external uniform pressure.	N. A. Alfutov.	Inzhenernyi Sbornik (Engineering Symposium), 1956, Vol. 23, p. 36.
Mechanical design of equipment.	Stability of a truncated conical shell under uniform external pressure.	L. M. Bunich, O. M. Palii and I. A. Piskovitina.	Inzhenernyi Sbornik (Engineering Symposium), 1956, Vol. 23, p. 89.
Mechanical design of equipment.	An approximate theory of tube expansion.	N. I. Glagolev.	Inzhenernyi Sbornik (Engineering Symposium), 1956, Vol. 23, p. 111.
Mechanical design of equipment.	A reflux divider for continuous rectification plants.	A. M. Smirnov.	Koks I Khimiya (Coal and Chemistry), 1957, No. 2, p. 60.

M. E. R. L.'s
NEW HEAT-TRANSFER LABORATORY

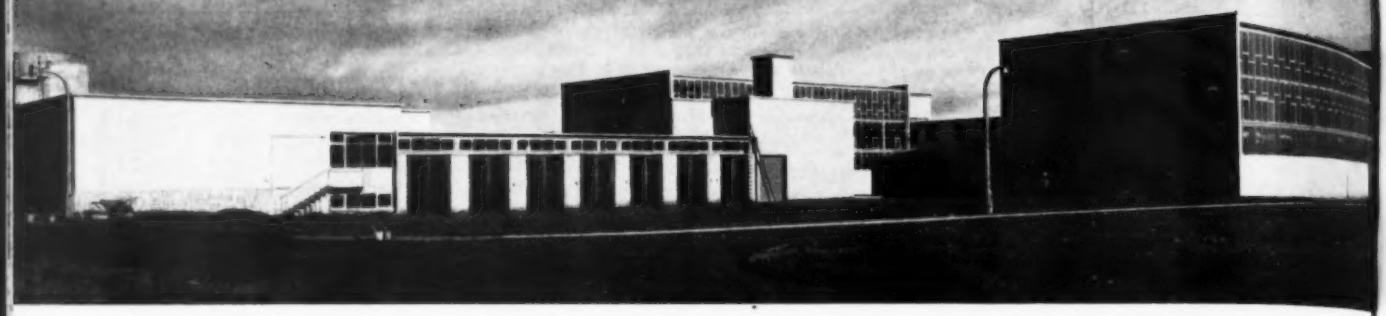

Fig. 1. The laboratory from the rear. Experimental bays are shown right and centre (background), and the engineering services block, left

The first laboratory specially designed for heat-transfer work at the Mechanical Engineering Research Laboratory has just been completed. Some details of it are described in this article

A NEW heat-transfer laboratory providing 15,000 sq. ft of experimental floor-space and liberally supplied with heating, cooling and other services has been completed for the Heat Division of the M.E.R.L. of the Department of Scientific and Industrial Research, East Kilbride, Glasgow. The accommodation includes two experimental bays 108 ft long, 50 ft wide and nearly 40 ft high; physics-type laboratories; and office space. Benefits from employing the new facilities will include an acceleration of the Division's work in pure and applied heat transfer and the thermodynamic physical and transport properties of fluids. An extension of the programme into important new directions, such as establishing fundamental heat-transfer data more precisely, semi-scale testing and analysis, should soon be possible if staffing difficulties can be overcome.

Flexibility in layout has been one of the aims in planning the laboratory, so that it will be adequate to cope with many kinds of problem and change of priorities that may arise during the foreseeable future. Appropriately, therefore, accessibility of services is a notable feature of the new building. Service pipes and cables are contained in large ducts, underground in the experimental bays and overhead in the physics-type laboratories. Offices could readily be converted, if necessary, to small laboratories; moreover, the building has been designed so that it may easily be extended. At present it consists of a front block 220 ft long with the experimental bays behind at each end. The physics-type laboratories are located in the front block on the ground floor and the offices occupy the first floor. Some distance behind the building lies the engineering services block and the boiler-house containing boilers, superheaters, transformers and cooling towers, which are operated by the Ministry of Works.

The experimental bays are tall, well-illuminated halls completely single-glazed on two sides. To minimise the heating and cooling effects of the weather, reflecting Venetian blinds have been fitted to the sides. Indeed, this form of insulation has been adopted generally in the laboratory. The west experimental bay, referred to as the "heavy bay", has been designed for investigations that need substantial quantities of services, and it will be used for, among other work, studies on complete pieces of equipment. It is built over a basement 8 ft deep to which the services are ducted. Access to the services may be gained by removing from the floor small tobie-plates or steel sections, and about one-half of the floor is removable in this way. Offtake of services is made available in the basement at a number of convenient points.

The east or "intermediate" bay (Fig. 2) will be used for research intermediate between that appropriate to a physics-type laboratory and that needing the heavy bay. It will include fundamental investigations requiring bulky apparatus and applied research that calls for great precision. A difference from the heavy bay is that along the whole of one side a gallery has been built. The gallery floor is removable so that lofty rigs may be installed. One-half of the basement has been left uncovered to receive a novel piece of equipment, a thermal convection tunnel. In this bay the services are raised from the basement to convenient points on the floor and gallery. Electrical and temperature standards, controlled in the adjacent standards rooms, are available from a terminal board in the bay.

The standards rooms occupy some of the physics-type laboratories in the front block, and, in the temperature-standards room, points on the international temperature scale, including those of sulphur, steam, gold and silver, will be maintained for checking the thermometry in the building. Other physics-type laboratories in the block include a still-air room for the conduction of natural convection experiments, heat transfer and thermophysics laboratories. A chemistry laboratory and photographic darkrooms are also accommodated in the suite. In the laboratories use is being made of a versatile demountable framework. Developed by the Division from a design used in the physics division of the National Physical Laboratory, it embodies uprights which may be either

supported on tapped bosses let into the floor or suspended from bosses in the ceiling (see Fig. 3). Cross-members are of channel section and may be supported at one end in wall sockets. The framework is stressed to support the heaviest piping likely to be used. The laboratories' services are taken directly from the duct which runs over the ground-floor corridor and projects partly into the rooms on each side. Any special service that may be required can readily be supplied through the duct. The duct entrances have been aligned with external doors in the building so that, if necessary, very long pipes may easily be carried in for installation.

The architecture of the new laboratory has been the responsibility of the Ministry of Works. The style is simple and the decoration colourful.

Laboratory Services

As electricity can easily provide a precisely controllable source of heat, it was decided early that a supply of electricity on a fairly considerable scale was essential for the laboratory. The total of a.c. and d.c. power is about 1750 kVA and plans provide for an increase to 2000 kVA if necessary. The supply has a number of novel features. For example, the voltage may be altered smoothly from maximum to zero. Although that kind of control presents no difficulty if the load is small enough to be fed from a variable transformer, more complicated gear than that has had to be installed, as loads up to 1000 kW are envisaged. The voltage of all supplies except that of the controlled frequency supply is stablished to within about $\pm\frac{1}{2}\%$.

Moderate powers of A.C. and D.C. are readily available from plug-in bus-bar systems and the variable voltage system provides a.c. power in five "blocks" of 200 kVA each, the voltage being stabilised and variable from 15 to 100%. Two or more blocks can be connected in parallel to provide powers of up to 1000 kVA. There is also a small supply of 240 volt A.C. controlled at a frequency of 50 c/s, $\pm 0.001\%$. Each experimental bay is equipped with a remote control switchboard on the variable system.

Three 100-psi boilers in the boiler-house nearby can produce 22,000 lb./hr of steam and this can be superheated to 750°F (maximum 10,000 lb./hr) or reduced to 15 psi (maximum 10,000 lb./hr). Steam at 750 psi and 750°F is also available (maximum 3000 lb./hr). Other services include cooling water (a total of 10 million Btu an hour can be dissipated by the two cooling towers); de-aerated water, a total of about 1500 lb./hr; compressed air, 2400 cu. ft/hr at 100 psi; and gas, 6000 cu. ft/hr.

Research Programme

Collecting and sponsoring thermodynamic observations, and, from existing and new figures, attempting to compile a consistent tabulation of these data is one of the main lines of work being undertaken by the laboratory at the moment. Although provisional tabulation has been made under supervision of the Thermodynamics Committee of the Mechanical Engineering Research Board, the laboratory aims now to produce improved tables. For the work it will soon have available a DEUCE computer. An endeavour is also being made to draw up internationally-acceptable tables of thermodynamics standards for about a score of technically-useful fluids including air, nitrogen, oxygen, hydrogen, carbon monoxide, carbon dioxide, some lower paraffins and less-rare inert gases such as helium and argon.

Other urgent tasks which could suitably be undertaken by the Division include that of exploring to what extent the analysis of equipment would be of value to industry and then of undertaking the appropriate analyses. On the side of fundamental research there is the task of accumulating precise heat-transfer data, and work already being conducted on heat transfer to mercury is of this kind. Research on the effect of bends and section change in pipes is providing useful training for the precision work.

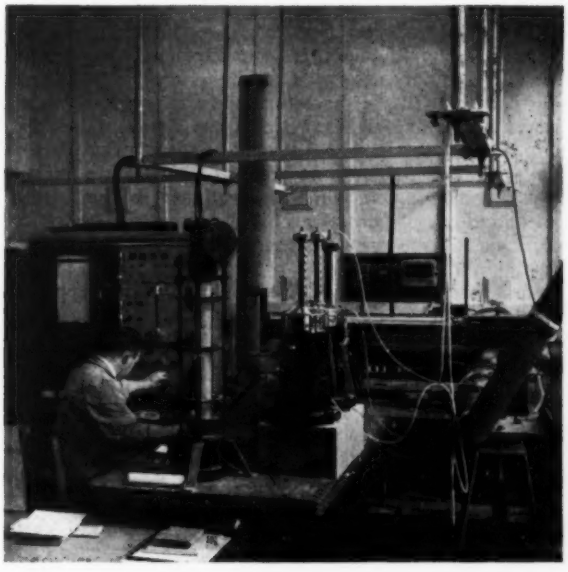

Fig. 2. Interior of the intermediate bay showing, top, the gallery and, bottom, the unenclosed section of the basement which is to receive the thermal convection tunnel. Fig. 3 (right). A physics-type laboratory. The apparatus shown is for measuring heat-transfer coefficients.

The Division has come into the possession of a building of its own after nine years of utilising accommodation of other departments. To what extent it will there be able to spread its wings and rise to even greater heights and wider prospects in the realms of mechanical and chemical engineering will depend on the supply of manpower. A temporary expedient suggested is for firms to send their own engineers to work on problems of mutual interest with the facilities provided by the laboratory.

Notes on the work at the laboratory on heat transfer to mercury, the effect on heat transfer of bends and sudden change of section regenerator beds, dropwise condensation and other problems were published in *British Chemical Engineering*, 1957, **2**, 88-90 and 467.

APPLICATION OF AUTOMATIC PROCESS CONTROL TO CHEMICAL ENGINEERING

Part 5: Response of Complex Process Stages*

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THE mathematical basis for control design is the differential equation governing the response of a process stage to a disturbance, and this is often the point at which the problem can go from the plant engineer to the control expert. It has been pointed out, however, that the derivation of this equation usually demands simplifying assumptions and in some cases it may be virtually impossible. This is not to say that control design is impossible in such cases, but it does mean that a different approach is required.

The simplest form of process stage has been shown to comprise a capacitance C and rate-factor q, which together yield a time constant $L = C/q$ characterising the differential equation. In the derivation, the analysis was rationalised by regarding all disturbances and deviations as inputs and outputs of control agent relative to unit deviation. An input signal or disturbance of θ_1 is equivalent to an input $q\theta_1$ of control agent, while a deviation θ_2 is equivalent to an output $q\theta_2$ of control agent. The accumulation of control agent in the system is then $q(\theta_1 - \theta_2)$ which causes a deviation change of $d\theta_2/d_t = (\theta_1 - \theta_2)q/C$. The response equation so derived is $L.d\theta_2/d_t + \theta_2 = \theta_1$, and it applies to all simple process stages.

This type of process stage is termed an exponential transfer stage in control literature because of the exponential form of response as shown in Equation (34).

Very few actual process stages are of this simple nature. Side capacitances and series complexes complicate the response often to the extent where the derivation of the basic differential equation and its solution are simply not worth the trouble involved. In some such cases it will be possible to determine the response characteristics by analogue or experiment, and in others the response of the process stage may be determinable *in situ*.

A useful introductory treatment of process stages is given in Young.[1] For analysis, a complex stage is broken down to simple process stages in series and parallel, and the whole stage can be treated much as an electrical network. The response of complex electrical networks has been treated extensively in the literature, but the stoichometrical approach as given in Young will appeal more to plant engineers. The rationalisation of units described in the first and the previous article in this series makes the treatment easier, and the method of analysis will now be used to deal with complex stages. Since a process stage can be defined as the smallest link in a process chain amenable to control, its further subdivision will be into substages. Three cases will be considered, and more complex process stages can be analysed using the same fundamental approach.

Case 1 (see Fig. 1)

COMPLEX STAGE COMPRISING TWO INDEPENDENT SUBSTAGES IN SERIES

If a process stage or substage is unaffected by the conditions in the following stage, the system is termed independent, although what happens in the preceding stage must affect the second stage. An example of a series of independent substages is a plate column, where the control agent is either liquid feed or reflux and the controlled variable is liquid level on the plates, the overflow from one plate to the next being independent of the level on the plate below. Two such plates would constitute two independent substages.

Another example would be a flow of water through two consecutive tanks, in each of which it is heated by live steam. If the normal flow rate of water through the system is W lbph, then the rate factor is $q \simeq W/1000$; i.e., the amount of live steam (control agent) to heat this flow of water through unit deviation, 1°F, and leaving the system or stage. This is the same for each substage (tank). The capacitance of each tank is the quantity of steam to heat the contents through 1°F, say C_x and C respectively.

For the liquid level system, the rate factor is the rate at which control agent (reflux or liquid feed—either of which is equivalent to downflow) leaves the plate per inch increase above normal level. If this is different for the two plates concerned, there will be two rate factors, q_x and q respectively. The capacitances will be the liquid held on the plates per inch of level, and will normally be the same, but if different will be C_x and C respectively, for each plate.

The derivation of the differential equation for either of the systems is the same. That for the liquid level will be developed because there are two rate factors involved. It covers the thermal system, where the same rate factor applies to each stage. The differential equation is derived by considering the changes in infinitesimal time at a moment when the transient values of the deviations from normal running are:

Input disturbance	θ_1
Out of balance in first substage	θ_x
Out of balance in second substage	θ_2

By definition, the input disturbance to the process stage is equivalent to the quantity of control agent leaving the

* *Previous parts were published in the May, June, August and October issues of* British Chemical Engineering.

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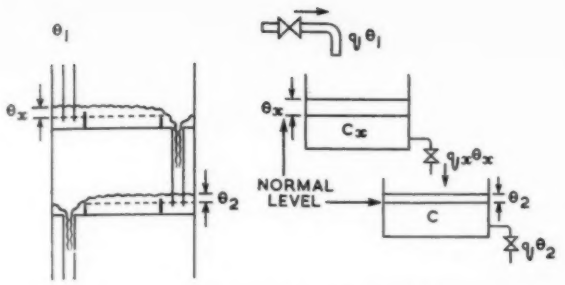

Fig. 1. System of independent substages by means of two plates of a distillation column.

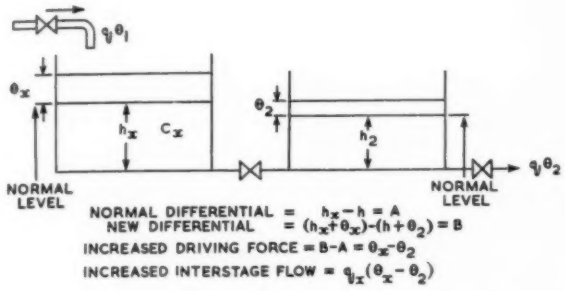
NORMAL LEVEL
NORMAL LEVEL
NORMAL DIFFERENTIAL = $h_x - h = A$
NEW DIFFERENTIAL = $(h_x+\theta_x)-(h+\theta_2) = B$
INCREASED DRIVING FORCE = $B-A = \theta_x-\theta_2$
INCREASED INTERSTAGE FLOW = $q_x(\theta_x-\theta_2)$

Fig. 2. Tank system typical of one in which interacting substages are present.

system at an equivalent deviation and is $q\theta_1$.

The out of balance or deviation in a stage or substage is equivalent to the quantity of control agent leaving that stage due to that deviation, and for the first substage this is $q_x\theta_x$. It is important that this differentiation in the use of the q_x and q rate factors be clearly understood. In the second stage, with a deviation of θ_2, the control agent output will be $q\theta_2$. The balances can now be struck.

First Substage (Capacitance C_x):

Control agent input in time $dt = q\theta_1 dt$

Control agent output in time $dt = q_x\theta_x dt$

Accumulation in first stage $= (q\theta_1 - q_x\theta_x)dt$.

This causes a deviation change $d\theta_x$ whence,

$$\frac{d\theta_x}{dt} = (q.\theta_1 - q_x.\theta_x)/C_x \qquad \ldots.(i)$$

Second Substage (Capacitance C):

Control agent input in time $dt = q_x\theta_x dt$

Control agent output in time $dt = q\theta_2 dt$

and similarly $$d\theta_2/dt = (q_x\,\theta_x - q\,\theta_2)/C \qquad \ldots.(ii)$$

rearranging, $$\theta_x = \frac{C}{q_x}\frac{d\theta_2}{dt} + \frac{q}{q_x}\theta_2 \qquad \ldots.(iii)$$

differentiating, $$\frac{d\theta_x}{dt} = \frac{C}{q_x}\frac{d^2\theta_2}{dt^2} + \frac{q}{q_x}\frac{d\theta}{dt} \qquad \ldots.(iv)$$

Substituting (iii) and (iv) in Equation (i) to eliminate θ_x and rearranging gives:

$$\frac{C_x}{q_x}\frac{C}{q}\frac{d^2\theta_2}{dt^2} + \left(\frac{C_x}{q_x} + \frac{C}{q}\right)\frac{d\theta_2}{dt} + \theta_2 = \theta_1 \qquad \ldots.(37)$$

which can be written as:

$$L_x.L\,\frac{d^2\theta_2}{dt^2} + (L_x + L)\frac{d\theta_2}{dt} + \theta_2 = \theta_1 \qquad \ldots.(37a)$$

where L_x and L are the time constants of the respective substages.

Case 2 (see Fig. 2)

TWO INTERACTING SUBSTAGES IN SERIES

An example of this type of complex stage is a flow of water being heated in a steam-jacketed tank where the heat capacity and thermal resistance of the heat-transfer surface are relatively small and can be neglected, the tank is perfectly insulated and the thermal capacity of the outer shell can be neglected.

Another example, frequently given in control literature, is a flow of water through two tanks in series, where back pressure from the second tank reacts on the flow from the first tank. This is a simpler case to analyse than the thermal example and will therefore now be examined since it is a process stage common in process work; it also illustrates an interesting point in control system design.

The capacitance of the steam side or first substage is the quantity of control agent (steam) to raise the temperature of the material in the substage (steam) by 1°F. Inspection of steam tables show that approximate linear relationships exist between steam density and pressure, and pressure and temperature respectively, over moderate temperature ranges, so that there is no difficulty in calculating the quantity C_x for the steam chest volume in the temperature range concerned. The rate factor q_x for the steam side is the rate at which control agent (steam) leaves for each 1°F deviation. This is the steam equivalent of the number of Btu transferred from steam to water side per 1°F temperature difference and is readily derived.

The capacitance C of the water side (second substage) is the quantity of steam necessary to heat the water content through 1°F, while the rate factor q is the steam equivalent to 1°F in the water throughput. In this example, the flow of control agent from the first substage to the second is dependent on the condition in that stage, and is proportional to $(\theta_x - \theta_2)$. With this consideration, the analysis follows the method of the previous derivation. At a moment when the instantaneous value of the disturbance is θ_1, the out-of-balance temperature on the steam side θ_x, and the deviation (out-of-balance temperature of the water) is θ_2, we have:

STEAM SIDE (Capacitance C_x)

Steam input $= q\theta_1 dt$

Steam output $= q_x(\theta_x - \theta_2)\,dt$

$$d\theta_x = \frac{\text{Accumulation}}{\text{Capacitance}}$$

$$= (q\theta_1 - q_x\theta_x + q_x\theta_2)\frac{dt}{C_x}$$

thus $$\frac{d\theta_x}{dt} = \frac{q\theta_1}{C_x} - \frac{q_x\theta_x}{C_x} + \frac{q_x\theta_2}{C_x} \qquad \ldots.(i)$$

WATER SIDE (Capacitance C)

Steam input $= q_x(\theta_x - \theta_2)\,dt$

Steam output $= q\theta_2\,dt$

$$d\theta_2 = \frac{\text{Accumulation}}{\text{Capacitance}}$$

and $$\frac{d\theta_2}{dt} = \frac{q_x\theta_x}{C} - \frac{q_x\theta_2}{C} - \frac{q\theta_2}{C} \qquad \ldots.(ii)$$

whence $$\theta_x = \frac{C}{q_x}\frac{d\theta_2}{dt} + \theta_2 + \frac{q}{q_x}\theta_2 \qquad \ldots.(iii)$$

and $$\frac{d\theta_x}{dt} = \frac{C}{q_x}\frac{d^2\theta_2}{dt^2} + \frac{d\theta_2}{dt} + \frac{q}{q_x}\frac{d\theta_2}{dt} \qquad \ldots.(iv)$$

Substituting (iii) and (iv) in Equation (i) as before to eliminate θ_x and rearranging, gives:

$$\frac{C}{q}\frac{C_x d^2\theta_2}{q_x dt^2} + \left(\frac{C_x}{q} + \frac{C_x}{q_x} + \frac{C}{q}\right)\frac{d\theta_2}{dt} + \theta_2 = \theta_1 \ldots.(38)$$

This equation, the use of which is shown later, cannot be simplified by introducing the time constants of the separate substages.

Case 3 (see Fig. 3)

SIDE CAPACITANCE. TWO INTERACTING SUBSTAGES IN PARALLEL

In the thermal system just discussed, if the disturbance θ_1 entered on the water side, the same process stage would then be a complex stage with side capacitance. While attention has been drawn in the literature to the importance of point of entry of a disturbance, this particular feature whereby a complex stage may behave both as series interacting substages or a single stage with side capacitance, does not appear to have been noted. Examples of complex stages with side capacitance are common in process work. Heat exchangers, furnaces and almost all processes where heat is transferred will include one or more side capacitances.

Making the broad approximation that the side capacitance has all the resistance concentrated at the boundary, a stage with one side capacitance is exemplified by the thermal system just discussed, with disturbance entry on the water side.

Taking the transient conditions as before, except that θ_1 is now entering the water side, the total input to the water side is now $q\theta_1$, the disturbance, plus the input from the steam side, $q_x(\theta_x-\theta_2)$. There is no input to the steam side. (It must be remembered that all quantities are additional to the main process which carries on, just as deviations are measured from the normal conditions.)

WATER SUBSTAGE (Capacitance C)

$$\text{Input} = (q\theta_1+q_x(\theta_x-\theta_2))dt$$

$$\text{Output} = q\theta_2\ dt$$

$$\text{therefore } d\theta_2 = \frac{\text{Accumulation}}{\text{Capacitance}}$$

$$= (q\theta_1-q\theta_2+q_x\theta_x-q_x\theta_2)\ dt/C$$

$$\text{whence } \theta_x = \frac{C}{q_x}\frac{d\theta_2}{dt} + \theta_2 + \frac{q}{q_x}\theta_2 - \frac{q}{q_x}\theta_1 \qquad \ldots.(i)$$

Differentiating we get:

$$\frac{d\theta_x}{dt} = \frac{C}{q_x}\frac{d^2\theta}{dt^2} + \frac{d\theta_2}{dt} + \frac{q}{q_x}\frac{d\theta_2}{dt} - \frac{q}{q_x}\frac{d\theta_1}{dt} \qquad \ldots.(ii)$$

STEAM SIDE CAPACITANCE (C_x)

$$\text{Input} = 0,$$

$$\text{Output} = q_x(\theta_x-\theta_2)dt$$

$$\text{thus } \frac{d\theta_x}{dt} = (\theta_2-\theta_x)\frac{q_x}{C_x}$$

Substituting in (i) and (ii) to eliminate θ_x and multiplying throughout by $\frac{C_x}{q}$, we get:

$$\frac{C}{q}\frac{C_x}{q_x}\frac{d^2\theta_2}{dt^2} + \left(\frac{C_x}{q}+\frac{C_x}{q_x}+\frac{C}{q}\right)\frac{d\theta_2}{dt} + \theta_2 = \theta_1 + \frac{C_x}{q_x}\frac{d\theta_1}{dt} \qquad \ldots.(39)$$

Contrary to what might have been expected, this equation gives the same result for a stepwise change, i.e. $\frac{d\theta_1}{dt} = 0$, as Equation (38) derived for Case 2; indicating that the response of this process stage to such a disturbance will be the same whether it occurs on the supply side or the demand side.

Distributed Stages or Substages

In deriving the differential equations, cases have been chosen, or simplifying approximations made, such that a simple stage or a substage effectively comprised a single capacitance and resistance (or flow rate) so that the derivation of the rate factor presented no problem. This will often be approximately the case in flow reaction systems, but only rarely in thermal systems where both resistance and capacity are distributed. The relevant difficulties are described by Young.[1] These difficulties can be partly smoothed by defining in terms of capacitance and rate factor rather than resistances and capacities, but, nevertheless, without simplifying approximations even the simpler cases are beyond reasonable mathematical treatment. The variable factors that occur in practical operation, such as change of heat-transfer coefficients with temperature, degree of fouling, flow rates, composition, and other variable factors, vitiate any precise derivation and would probably introduce more uncertainty and error than would simplifying approximations. The circumstances of any particular case would decide what approximations to introduce, and, using the principles outlined in this article, it should be possible to derive stoichometrically a basic equation which would describe the response of a complex process stage reasonably well.

EXAMPLE: Derive the response equation for a reaction vessel in which a mixture with heat capacitance 0.8 Btu/lb. entering at 70°F is heated to 180°F. The vessel is a steam-jacketed cylindrical tank holding 2000 lb. of mixture and the free volume of the steam jacket is 6.5 cu. ft. Steam at 75 psia heats a throughflow of 10,000 lbph of mixture in this vessel. Assume no heat losses and negligible thermal capacitance of the walls.

ANSWER: Capacitance of steam substage, C_x. Control agent, steam. The capacitance is the quantity of steam equivalent to a 1°F change in the steam jacket temperature.

From Steam Tables

Pressure	Temp.	lb. steam/cu.ft.	Temp. interval	Density increment
70 psia	302.9°F	1.61	—	—
75 ,,	307.6	1.72	4.7°F	0.11 lb. cu. ft.
80 ,,	312.0	1.83	4.4°F	0.11 ,, ,,

From the steam values it is seen that a 1°F temperature rise in the steam chest is equivalent to a steam quantity of

$$\frac{0.11}{4.55} \times 6.5 = 0.17 \text{ lb. steam} = c_x$$

RATE FACTOR OF STEAM SUBSTAGE, q_x

This is the rate at which heat (as steam) is transferred to the reagent side, per 1°F temperature difference.

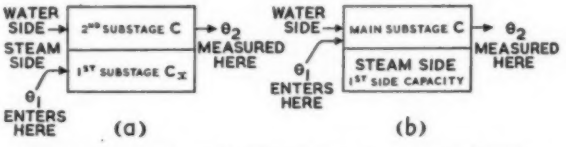

Fig. 3. (a) Heat exchanger acting as two substages in series. (b) The same exchanger acting as a main substage with side capacitance.

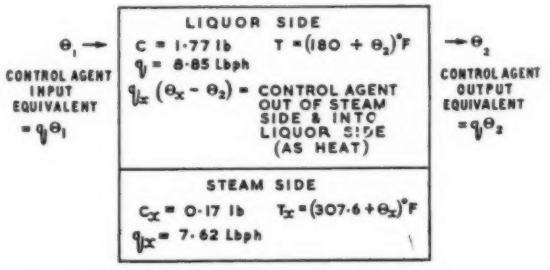
θ1
CONTROL AGENT INPUT EQUIVALENT = qθ1
LIQUOR SIDE
C = 1·77 lb
T = (180 + θ2)°F
q = 8·85 Lbph
qx (θx - θ2) = CONTROL AGENT OUT OF STEAM SIDE & INTO LIQUOR SIDE (AS HEAT)
θ2
CONTROL AGENT OUTPUT EQUIVALENT = qθ2
STEAM SIDE
Cx = 0·17 lb
Tx = (307·6 + θx)°F
qx = 7·62 Lbph

Fig. 4. Effect of disturbances entering either the steam side or water side in hypothetical heater.

At a temperature difference of 307.6 − 180°F, the heat transferred is $10{,}000 \times 0.8 \times (180 - 70)$ Btuph $= \frac{880{,}000}{905}$ = 972 lbph steam.

At a temperature difference of 1°F, heat transferred $= \frac{972}{(307.6-180)} = 7.62$ lbph steam $= q \times L$

CAPACITANCE OF REACTANT SIDE, C

2000 lb. of mixture at 1°F are equivalent to:

$$C = 2000 \times 0.8 = 1600 \text{ Btu} = \frac{1600}{905} = 1.77 \text{ lb. steam.}$$

RATE FACTOR OF REACTANT SIDE, q

This is the steam equivalent of 10,000 lbph of mixture at 1°F.

$$q = \frac{10{,}000 \times 0.8}{905} = 8.85 \text{ lbph steam.}$$

Substituting in Equation (38):

$$\frac{C}{q}\frac{C_x}{q_x}\frac{d^2\theta_2}{dt^2} + \left(\frac{C_x}{q} + \frac{C_x}{q_x} + \frac{C}{q}\right)\frac{d\theta_2}{dt} + \theta_2 = \theta_1$$

$$\frac{1.77}{8.85} \times \frac{0.17}{7.62} \times \frac{d^2\theta_2}{dt_2} + \left(\frac{0.17}{8.85} + \frac{0.17}{7.62} + \frac{1.77}{8.85}\right)\frac{d\theta_2}{dt} + \theta_2 = \theta_1$$

whence $$0.00446\frac{d^2\theta_2}{dt^2} + 0.2415\frac{d\theta}{dt} + \theta_2 = \theta_1$$

The constants in this equation are in hour units.

Operating under control, the controlling factor will be valve movement, which would be related to steam supply and unit deviation by a disturbance correlation factor as explained in the first article. This example could equally have been worked in Btu with heat as the control agent. The same equation would have been derived.

The preceding example may be used to illustrate the precise effect of a possible disturbance and the mechanism of the various transfers (Fig. 4).

Suppose the disturbance to be a step change $\theta_1 = +3°F$. The potential deviation is then also +3°F and the equilibrium temperature of the liquor side 183°F. If θ_1 enters the liquor side, it can do so either as an increased inlet temperature of 3°F or as a reduced liquor rate. The steam consumption being unchanged, and no change in the quantity of heat transferred from steam to liquor side, means that at equilibrium the steam temperature will also have increased by 3°F to keep the driving temperature difference unchanged. The equilibrium value of θ_x will be 3°F and $T_x = 310.6°F$. The pressure in the steam chest will accordingly be higher.

If θ_1 enters the steam side, it will do so as an increased steam input of $3 \times 8.85 = 26.55$ lbph. At equilibrium, all this extra heat will be passing over to the liquor side. Now a normal temperature difference of 307.7 − 180 = 127.6°F serves to transfer heat to raise the liquor through 180 − 70 = 110°F. To raise the liquor through a further 3°F will require an additional temperature difference of

$$\frac{127.6}{110} \times 3 = 3.48°F$$

The equilibrium temperature of T_x will then be 307.6 + 3 + 3.48 = 315.08°F, with a corresponding higher pressure in the steam chest. In each case the mode of approach to equilibrium will be given by the integrated form of Equation (38) or (39).

REFERENCE

[1] Young, A. J. "An Introduction to Process Control System Design", Longmans Green, London, 1955, p. 257.

De Nora Secure International Contracts

RECENTLY, THE ITALIAN firm Oronzio de Nora, Impianti Elettrochimici, Milan, secured a contract for the supply of electrolysers to the value of about £2.5 million to be installed at the Nangal Fertiliser and Heavy-water Project in the Northern Punjab, India. The project is scheduled to be completed by the end of 1959 and full production should be reached early in 1960. Eighty thousand tons of nitrogen are expected to be produced annually in the form of ammonium nitrate and nitrochalk, while the production of heavy water is expected to reach 15 tons a year. De Nora equipment will begin to be delivered in March, 1958, and delivery is to be completed by April, 1959. Some 6500 cells grouped in 60 electrolysers of the filter-press type, each rated at 10,000 A, will be installed. They will enable more than 25,000 cu. m. of hydrogen to be produced hourly. The power required by the electrolysers will be approximately 140,000 kW, which will be made available from the Bhakra Nangal power station.

One of the considerations which determined the choice of de Nora plant was the relatively high figure which this company was able to guarantee with regard to the separation factor of deuterium. This will enable the related production of heavy water to be increased above that which was originally estimated. Each de Nora electrolyser consists of a battery of bipolar cells tightly clamped together so as to form a filter-press-type assembly. The electrodes are mounted in pairs, each being supported and divided by a central metallic plate. The electrodes facing each other are separated by a double diaphragm which is considered to be more advantageous than the unipolar cell system. Current feeding connections are only necessary to and from the first and last electrodes, with a considerable reduction on ohmic tension drops. The compact nature of the assembly achieves a saving in floor space and enables the gas to be delivered at the required pressure without the use of a blower. The two pressure valves which govern the delivery of hydrogen and oxygen are independent of each other and there is no possibility of the two gases mixing. The double diaphragm between each anode and cathode is a particular feature of the de Nora electrolysers. An intermediate chamber is thus formed which prevents even the smallest quantities of hydrogen and oxygen from passing into the other gas compartment. The small amounts of gas which normally escape and enter the stream of the other gas are thus diverted into the central chamber and discharged outside the cell. The purity of the product is greater than that obtained by means of a single diaphragm.

The electrodes are made of perforated mild-steel plates. The anodes on which oxygen forms are heavily nickel-plated to ensure that overloading is kept at a reasonably low level. The cathodes, on the other hand, are submitted to an activating process which increases the surface porosity, thereby reducing the hydrogen overloading of the iron.

Consumption figures based on 1 cu. m. H_2STP are electric energy, 5 kWh; electrolysis water, 0.9 litres; cooling water, 45 litres; and caustic potash, 0.4 litre.

Quality of products—

guaranteed purity:	Hydrogen	99.8 ± 0.2 %
	Oxygen	99.6 ± 0.2 %
normal purity:	Hydrogen	99.9 %
	Oxygen	99.7 %

Among the orders secured from South American countries are the furnishing of a caustic soda-chlorine plant to Panamericana Textil S.A., Sao Paulo, Brazil, and the designing and building of a large chlorine-producing plant at Bogota, Colombia, for Planta Colombiana de Soda.

DOES FOULING OF HEAT-EXCHANGER SURFACES ALWAYS MEAN POORER PERFORMANCE?

This article discusses the proposition that dirt deposits invariably mean poorer heat transfer in heat exchangers. The conditions under which the reverse is the case are outlined for fouling inside exchanger tubes and on the plates of plate exchangers

THE general view is that the build-up of fouling deposits upon the surfaces of heat exchangers affects adversely their performance. To the designer it is useful to know how heat-transfer coefficients vary with increasing thickness of deposits and how the quantities of heat transferred also vary.

The case where the interior surface of shell and tube exchangers becomes fouled will be considered first. If the fluid velocity through the tubes or if the pressure loss is maintained constant, then fouling will mean less heat transfer, assuming an unchanged temperature difference between heating and cooling fluid. On the other hand, if the volume of fluid passing through the tubes is kept constant, it is possible for higher rates of heat transfer to arise, but this will be at the expense of a greater pressure loss. This latter case will now be discussed.

The film coefficients in the tubes will be given by the expression:

$$Nu_c = a\ Re^m\ Pr^n \qquad \ldots.(1)$$

If the Prandtl number does not vary in the presence of the material deposited on the tubes, then the quantities of heat transfer under clean-wall and fouled-wall conditions respectively for the same temperature difference are given by:

$$Q_c = \frac{\pi L \triangle T}{\frac{1}{h_c D} + \frac{1}{2k} ln \frac{D+2t}{D} + \frac{1}{h_o (D+2t)}} \qquad \ldots.(2)$$

$$Q_d = \frac{\pi L \triangle T}{\frac{1}{h_d (D-2t_d)} + \frac{1}{2\,k_d} ln \frac{D}{D-2t_d} + \frac{1}{2k} ln \frac{D+2t}{D} + \frac{1}{h_o (D+2t)}} \qquad \ldots.(3)$$

Also $h \propto V^m D^{m-1}$ and with a constant delivery from the feed pump $V \propto D^2$.

The velocity ratio for the clean and dirty tubes is then given by:

$$\frac{V_c}{V_d} = \left(\frac{D-2t_d}{D}\right)^2 \qquad \ldots.(4)$$

since $h_c \propto V_c^m D^{m-1}$

and $h_d \propto V^m{}_D (D-2t_d)^{m-1}$

then $$\frac{h_c}{h_d} = \left(\frac{V_c}{V_D}\right)^m \left(\frac{D}{D-2t_d}\right)^{m-1} = (1-2\beta)^{m+1} \qquad \ldots.(5)$$

where $$\frac{t_d}{D} = \beta$$

Symbols

- a = a constant;
- b = width of slot or clearance between adjacent plates;
- c = specific heat of fluid, or subscript denoting clean conditions;
- D = internal diameter of tube;
- h = film coefficient of heat transfer;
- h_c = film coefficient for clean tubing;
- h_d = film coefficient when tubes are fouled;
- h_o = film coefficient at outer surface of tubes;
- k = thermal conductivity of tube-wall material;
- k_d = thermal conductivity of fouling deposit;
- m = exponent of Reynolds number;
- n = exponent of Prandtl number;
- Nu = Nusselt No., $\frac{hD}{k}$;
- Pr = Prandtl No., $\frac{c\mu}{k}$;
- Q_c = amount of heat transmitted under clean tube-wall conditions;
- Q_d = amount of heat transmitted with fouled tube walls;
- Re = Reynolds No., $\frac{DV\rho}{\mu}$;
- t = tube-wall thickness;
- t_d = mean thickness of dirt layer on tube wall;
- V = velocity of fluid through exchanger;
- V_c = velocity with clean tubes;
- V_d = velocity with fouled tubes;
- $\triangle T$ = mean temperature difference; and
- β = ratio of mean thickness of dirt layer to tube internal diameter, t_d/D.

Thus $$h_d = \frac{h_c}{(1-2\beta)^{m+1}}$$

and $$\frac{1}{h_D(D-2t_d)} = \frac{(1-2\beta)^m}{h_c D} \qquad \ldots.(6)$$

The term $(1-2\beta)^m$ can be expanded in series, and if β is much less than unity, then $(1-2\beta)^m = 1-(2\beta)^m$

and $$ln \frac{1}{1-2\beta} \simeq 2\beta$$

substituting in Equations (2) and (3) and dividing we get

$$\frac{Q_c}{Q_d} = 1 + \frac{\frac{\beta}{h_c D}\left(\frac{h_c D}{k_d} - 2m\right)}{\frac{1}{h_c D} + \frac{1}{2k} ln \frac{D+2t_d}{D} + \frac{1}{h_o (D+2t_d)}} \qquad \ldots.(7)$$

The denominator of this equation will invariably have a positive value, but the numerator can be either negative or positive. Writing the dimensionless term $\frac{h_c D}{k_d}$ which has the appearance of a Nusselt number $= Nu_d$, we have:

$$Q_d < Q_c, \text{ when } Nu_d > 2m;$$
$$\text{and } Q_d > Q_c, \text{ when } Nu_d < 2m.$$

Hence when the volumetric throughput of the fluid passing through the tubes is constant, it is theoretically possible for a greater quantity of heat to be transferred with fouled tubes than with clean tubes; but owing to the greater velocity and the possibility of a rougher surface, the pressure loss will be greater than with clean tubes. When $Nu_d = 2m$, the quantities of heat transferred are the same in both cases and are unaffected by the deposit of dirt upon the tube surfaces, provided that the deposit is small, i.e., β is small.

Where layers of considerable thickness occur the approximation made in taking the first term of the series expansion is no longer valid. Two cases can be considered where appreciable build-up occurs.

(1) Where the coefficients on either side of the metal wall are approximately the same.

(2) Where the external coefficient is very much greater than the interior one. In the first case:

$$\frac{1}{h_c D} = \frac{1}{h_o(D+2t)} + \frac{1}{2k} \ln \frac{D+2t}{D} \quad \ldots . (8)$$

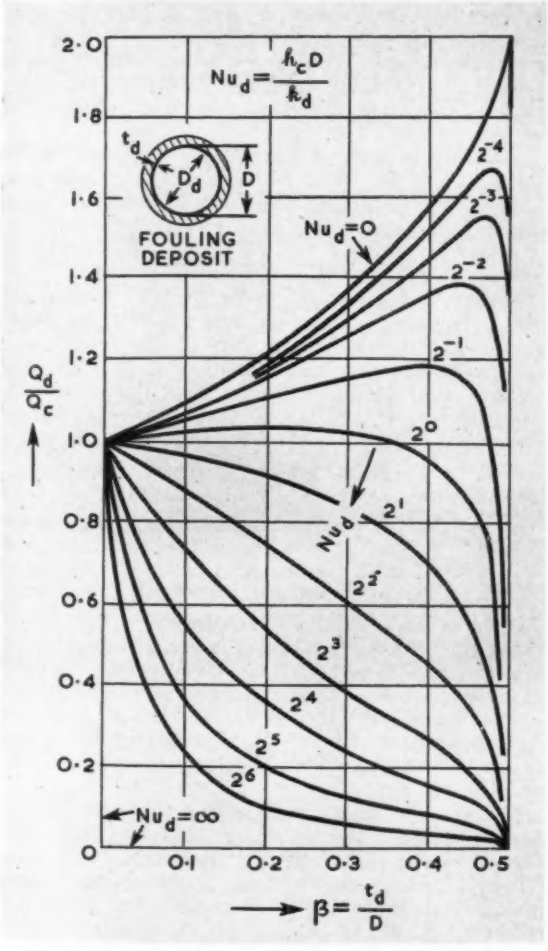

Fig. 1. Ratio of heats transferred for fluid flowing inside tubes for fouled and clean tubes ($h_c \simeq h_o$).[1]

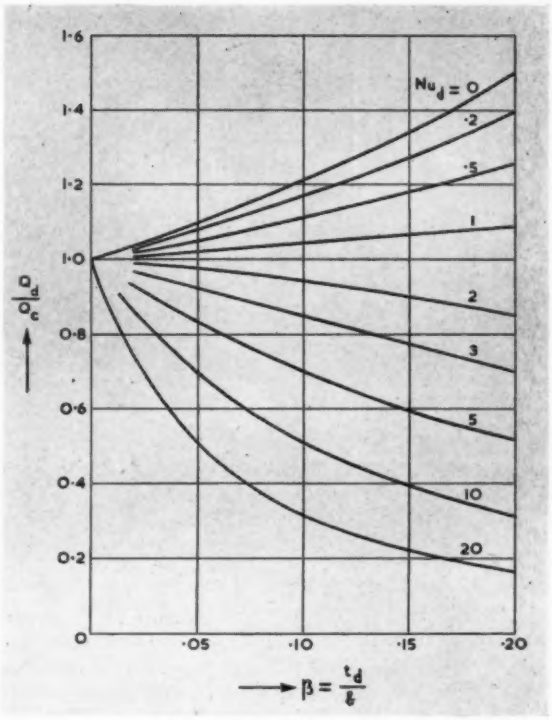

Fig. 2. Ratio of quantities of heat transferred for fluid flowing inside tubes for fouled and clean tubes respectively ($h_o \gg h_c$).

substituting in Equations (2) and (3) and dividing we get:

$$\frac{Q_d}{Q_c} = \frac{2}{1 + (1-2\beta)^m - \frac{1}{2} Nu_d \ln (1-2\beta)} \quad \ldots . (9)$$

This equation is used to produce the family of curves shown in Fig. 1, which allows the ratio $\frac{Qd}{Qc}$ to be determined for different degrees of scaling, for different values of Nu_d, and for $m = 0.8$. For large film conductances, that is for high values of Nu_d, the curves show that even quite slight deposits add sufficient resistance to affect seriously the total quantity of heat transferred. On the other hand, where film coefficients are low the curves show that it is possible for fouling to improve heat-transfer rates.

For the case where the external coefficient is much greater and the metal wall resistance much less than the interior film coefficient

$$\frac{Q_d}{Q_c} = \frac{1}{(1-2\beta)^m - \frac{1}{2} Nu_d \ln (1-2\beta)} \quad \ldots . (10)$$

Fig. 2 shows a group of curves produced by means of this equation.

Estimating Total Heat Transferred

The use of Fig. 1 or Equation (9) may be illustrated by means of an example of a gas-to-gas heat-exchanger design given in the literature[2] which has external and internal film coefficients of similar magnitude. The following details of this design calculation are relevant to this comparison: inside film coefficient = 26.2 Btu/hr ft² 1°F; outside film coefficient = 21.2; overall coefficient neglecting fouling = 13.4; tube OD = 1.00 in.; and tube ID = O.782 in. If it is now assumed that a fouling deposit is formed upon the inner surface of the tubes, two methods of assessing the effect of scale are available. Let $k_d = 1.2$ and let the thickness of the deposit be 0.04 in., assuming it to be

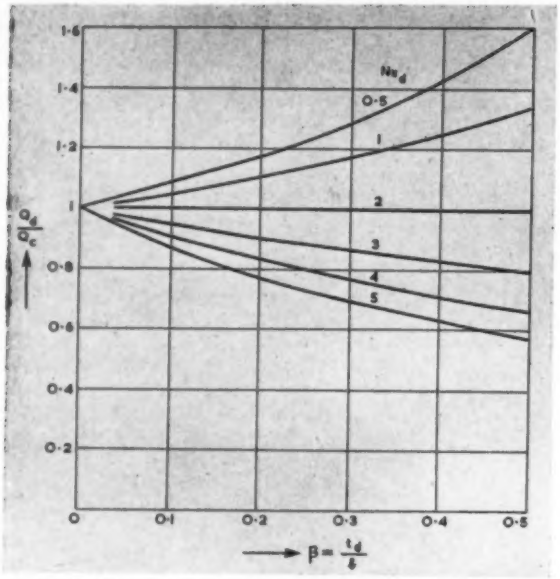

Fig. 3. Ratio of quantities of heat transferred for fluid flowing in plate exchangers for fouled and dirty conditions respectively.[1]

uniformly distributed over the interior surface of the tubes. The effect may be expressed by a fouling factor

$$= \frac{2k_d}{D \ln \frac{D}{D-2t_d}} = 352 \text{ Btu/hr ft}^2\ 1°\text{F}$$

The overall coefficient by the usual method of calculation is then given by

$$U_d = \frac{13.4 \times 352}{13.4 + 352} = 12.9 \text{ Btu/hr ft}^2\ 1°\text{F},$$

and assuming that the mean temperature difference remains unchanged this gives

$$\frac{Q_d}{Q_c} = \frac{12.9}{13.4} = 0.96.$$

Fig. 1 or Equation (9) provide another approach to this problem.

$$Nu_d = \frac{26.2 \times 0.782}{12 \times 1.2} = 1.41$$

$$\text{and } \beta = \frac{0.04}{0.782} = 0.052.$$

From Fig. 1 or Equation (9), $\frac{Q_d}{Q_c} = 1.01$.

This shows that if the throughput of fluid through the tube can be maintained then the heat transferred will not diminish with fouling of the tube interior. The conventional method of including the fouling factor in the overall coefficient gives a conservative estimate of the heat transferred in this particular case and leaves out of account the increased pressure drop.

Plate Exchangers

For plate-type exchangers and other types where the section of transverse to flow is slot-like, the ratio of clean to dirty coefficients is given by:

$$\frac{h_d}{h_c} = \frac{b}{b-2t_d} = \frac{1}{1-2\beta}$$

where $\beta = \frac{t_d}{b}$.

In this case, where the length of the slot is affected but slightly by the fouling deposit, the decrease in slot area produces a corresponding increase in fluid velocity, but the Reynolds number remains substantially constant. If it is assumed that the resistance to heat flow on both sides of a plate is constant, then:

$$\frac{1}{h_c} = \frac{1}{h_o} + \frac{t}{k}$$

and for the ratio of the heat quantities transferred for dirty and clean conditions respectively the following expression can be derived:

$$\frac{Q_d}{Q_c} = \frac{2}{2 + (Nu_d - 2)} \qquad \ldots\ldots(12)$$

where $Nu_d = \frac{h_c b}{k_d}$.

In Fig. 3 a family of curves is plotted to show how the ratio of heats transferred for clean and dirty conditions varies with Nu_d and with different degrees of fouling. Unlike the tubular exchanger, the heat transfer does not fall to zero when the thickness of the deposit approaches one-half the width of the slot, for under these conditions the velocity approaches infinity. For values of Nu_d less than two, the quantity of heat transmitted increases with increasing thickness of the fouling layer.

From the designer's angle the foregoing equations and graphs may be useful for specifying correctly the performance of the feed pump or compressor which has to deliver a constant volume of fluid through the heat-exchange apparatus. This applies particularly where fouling is to be expected. When an exchanger's surface is being estimated, the calculation need not take account of fouling in tubular equipment if Nu_d, as previously defined is less than $2m$.

In the case of plate exchangers, the same will hold if Nu_d is less than two. If an exchanger design is made with an allowance for fouling and increased velocity due to reduced cross-sectional area, it is possible, if fouling does not actually take place, for the actual heat transmission performance to fall short of that expected.

The foregoing treatment of the effect of fouling has, as has been mentioned, assumed turbulent flow and fouling on one side of a heat transfer surface only. A number of other combinations can exist, depending upon whether the fluids are in turbulent or streamline flow, and whether the fouling occurs on both sides of the heat transfer surface. Some of the possible combinations will be examined in a forthcoming article to be published in this journal.

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[1] Gregorig, R. "Escher Wyss News", 32, 29, No. 3. 1956.
[2] McAdams. "Heat Transmission", third edition, McGraw-Hill Book Co., London, 433-4.

ERRATA TO OCTOBER AND NOVEMBER ISSUES

IN THE ARTICLE "Design, Operation and Application of Grid Trays", which was published in our October issue, the last sentence in the paragraph on "Constructional Details", p. 546, should read: "One application of this principle is the Thermagrid tray[22] (British Patent 742,284) which employs tubes instead of bars." To the References given on p. 547 should be added: "Reference 22—Anon. *Brit. Chem. Eng.*, 1957, **2**, 280."

The authors of the article "The Steam Tracing of Pipelines", which was published in our November issue, have informed us that in the section "Mechanical Construction of Tracing", p. 598, the first sentence should end "... and for welds as illustrated in Fig. 4". In the section on "Design Procedure", p. 600, the fifth sentence should end "... welds of 2 in. length on alternate sides of the tracing pipe as shown on Fig. 4, using a single tracer".

USE OF BURSTING DISCS AT HIGH TEMPERATURES

THE bursting disc is widely employed in the chemical industry for the purpose of protecting vessels and operators from the effects of rapid build-ups of excessive pressure. As a safety measure it avoids the disadvantages of the safety valve, which has the tendency to gum up and to suffer damage to its seatings through corrosion. The materials now available for discs are sufficiently reliable for bursting to take place within a very close margin of the required pressure, however, bursting pressures change appreciably with even quite small changes in temperature. Unfortunately, this variation in bursting pressures has not been predictable, with the result that the use of discs has been limited. This limitation is underlined by the present-day trend to reactions carried out at high temperatures and pressures, some of which require safety devices with the characteristics of bursting discs.

It is of interest to see therefore how far the three papers[1] given recently contribute to the scanty knowledge of this temperature effect.

All the papers gave results of tests carried out on various disc materials and, as a result, were able to make some tentative recommendations. These are shown in the graphs of T. B. Philip (not given here) and H. R. Wright (Fig. 5), whereas suggested temperature limits were given by J. F. W. Brown in his Table V. Values for the ratio operating pressure: bursting pressure were given for a number of materials (Wright).

The effect of time to attain bursting pressure upon the latter was discussed also and some data illustrating the effect were given in Table I of Philip's paper. The need, however, for more information on this effect was stressed, particularly for applications where the time to reach bursting pressure would be extremely small, and where there was a possibility of pressure build-up even after rupture.

Creep, the property of the disc material which causes it to stretch continuously when loaded at elevated temperatures, contributes more than any other property to bursting pressures at high temperatures being lower than would be expected from short-duration tests. Our knowledge so far will not enable us to predict the effect of creep quantitatively upon bursting pressures. However, the figures given in Table III take the effect into account. It will be noted, however, that the maximum temperature covered by these recommendations is 175°C. Of disc materials, silver and aluminium are particularly susceptible to creep, but Monel is one of the least affected. Furthermore Monel has other properties, including corrosion resistance, which make it one of the best disc materials.

The effect of creep upon a silver disc was described. This was used in a reaction vessel and was designed to burst in the pressure range 280-300 psi at ambient temperature. In practice, the temperature was 70-80°C; the operating pressure was 150 psi for a period of reaction, etc., of 14 hours. The bursting pressure was reduced to 250-270 psi, but, more serious, the disc failed at the early stages of a reaction if used a second time. These premature failures were prevented by resiting the disc housing in such a position that its temperature was little different from that of the atmosphere.

Ductility is another property of disc materials likely to decrease at elevated temperature. To reduce this effect it was suggested that discs should be dished to an angle of 40 degrees at room temperature. This suggestion was supported by the results of tests which show a steady increase of bursting pressure with dish angle and pre-dishing pressure. The curves of Fig. 5 (Wright) assume that the angle of dishing is less than 40 degrees.

Among other points of practical value which emerged from discussion were that metallic discs with good properties but lacking corrosion resistance for a particular application could be protected by employing a coating such as araldite or Kel-F. Such coatings did not add any appreciable strength to the disc. The practice of using bursting discs without designing the vessels to take them was considered a mistaken one.

Thus, while this group of papers is of service to the practical man and some of the temperature effects are now more clearly defined, a great deal more work needs to be done, particularly on creep, before discs can be used more widely as safety devices at high temperatures. Carbon and titanium were not mentioned.

REFERENCE

[1] The Effect of Temperature on Bursting Discs. Three Papers given to the Institution of Chemical Engineers on October 7, 1957, by H. R. Wright (I.C.I., Billingham), T. B. Philip (Distillers Co., Epsom) and J. F. W. Brown (Johnson, Matthey & Co. Ltd.).

TABLE III. Maximum Recommended Values of Ratio (Operating Pressure)/(Short Time Bursting Pressure at Operating Temperature)

Material of disc	Recommended maximum value of ratio: (Operating pressure) (Short time b.p. at op. temp.) at 20°C	60°C	150°C	175°C
Aluminium	0·7	0.4	Zero	—
Silver	0.6	—	Zero	—
Copper	0.7	—	—	—
Nickel	0.95	—	—	0.9
18/8/Ti	0.95	—	—	0.9

TABLE V.—Suggested Limits of Working Temperatures for Bursting Discs

Silver	150°C
Aluminium	100°C
Copper	200°C
Nickel	400°C
Palladium alloy	300°C
Platinum alloy	400°C
Gold	80°C

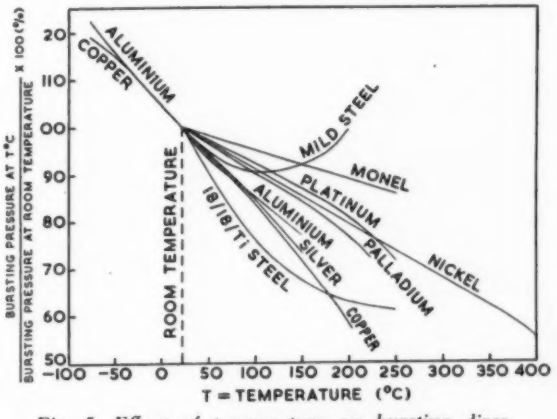

Fig. 5. Effect of temperature on bursting discs.

AMERICAN LETTER

Developments in American Technology

ALMOST daily new advances are announced in the American processing, engineering and instrumentation fields, and the following interesting examples are typical of numerous recent developments that can lay claim to being new.

It has been reported that a unique class of structural materials has been discovered—partly accidentally—by scientists of the Corning glassworks. These products, called Pyrocerams, have special properties which give them a great potential in both the aeronautical and the chemical industries. They are said to be outstanding as regards strength, hardness, deformation, shock and electrical insulation, as well as chemical inertness. For instance, one Pyroceram is lighter than aluminium, softens at about 1350°C—higher than some alloy steels—and has a tensile strength of 20 tons a sq. in., even at a high temperature. The applications of such a material to high-speed flight promise to be many. Other Pyrocerams have been developed which show excellent resistance to strong acids and alkalis, plus a high hardness and resistance to thermal and mechanical shock. These materials should find a ready use in the chemical field for pump parts, valves and many other items, since it is envisaged that they will cost less than equivalent parts made from stainless steel. Pyrocerams are said to be made from glass which has been nucleated by special means. Crystal size may be as small as 100 Angstrom units. Forming can be carried out by conventional glass- or metal-working methods, such as drawing, spinning, casting or pressing, followed by heat treatment to give a fine, crystalline structure with specific properties according to chemical composition and the heat treatment given.

Few people, either inside or outside the United States, have ever seen or heard of Gilsonite. This is a naturally-occurring black, asphalt-like mineral found in a remote part of Southern Utah. In view of its high resin content and good acid-resisting and insulating properties, Gilsonite aroused early attention as a potential material for tank linings, mouldings and lacquers. However, the difficulties of mining and transportation made the cost of such a raw material prohibitive in many cases. The establishment of large-scale industries such as iron and steel, in the Intermountain area and the growth of aluminium smelting in the North-west have created a market for high purity coke, in addition to a widespread demand for locally-produced gasolene. Modern technology and money—about $20 million—has enabled Gilsonite to be used for these purposes, and a few weeks ago the first large-scale refinery using this basic raw material went on stream. The plant has a daily production of about 270 tons of coke and some 1400 barrels of gasolene from some 650 tons of the mineral; proven reserves are sufficient for many decades of operation at this output level.

Mining and transportation difficulties have been overcome by bold, but simple methods. High-pressure water jets are used at the face, as compared to the older pick-and-shovel way, and transportation is effected by means of a 6-in. pipeline over 70 miles in length, which rises at one point to over 8500 ft. The slurry, containing about 35% Gilsonite, is dewatered at the refinery on a disc filter to yield a solid crude at a delivered price less than $2 a barrel, which compares extremely favourably with an average delivered price for U.S. crude of $3.20 a barrel.

In addition to yielding a high-grade coke and low-cost gasolene, it is anticipated that Gilsonite may prove to be a valuable source of chemicals for the Western States. Already ammonia and associated products are being produced on a small scale, since the material contains nitrogen compounds capable of hydrogenation. Another possible development is the production of resinous and plastic-type compounds with specific properties, which should be invaluable for certain industrial applications.

Processes for increasing the hardness of castings and machined components by chromium diffusion have been available for some time. Recently this principle has been adapted to manufacture corrosion-resistant steel plate and fabrications from mild steel, at a cost which is said to be only 40 to 50% of equivalent stainless steels. The process involves heating the mild-steel plate or fabrication, together with a selected chromium compound, in a closed vessel for several hours at about 1100°C. A chromium-bearing atmosphere is produced, which is reduced by the iron, and deposits chromium on the surface of the plate. Chromium gradually diffuses into the boundary structure and also forms an alloy product in the grain. It is said that a gradient from about 40 to 15% chromium is formed, with a sufficient depth of penetration to avoid case-hardening. This results in a ductile, workable metal. If a high-carbon steel is used, chromium carbide is formed, with a Vickers hardness of 2000 or so resulting. This will necessitate special heat treatment after further welding. Corrosion-resistant plate made by this process is now offered by several firms, such as the Chromalloy Corporation, from about 50 cents a pound upwards.

New Dust Collectors

There is no doubt that bag-type dust collectors have their drawbacks, yet they are still widely used when a high recovery of dust is essential for economic or for health reasons. One principal weakness is the necessity for frequent shaking-down and purging; this is accomplished in many ways, ranging from a periodic beating by some dusty operator to mechanical or pneumatic schemes of great complexity. This, in turn, can lead to a very poor performance, as well as a greatly reduced bag life which may prove expensive. A fresh approach to this problem is seen in the "Pulsaire" collector offered by the Metals Disintegrating Co., in which a timed, periodic discharge is effected by a blast of air only. The bags are suspended in a chamber and filter out the dust particles as the gas passes through the bags to an outlet manifold, via a venturi-shaped exit nozzle at the top of each bag. Dust is removed from the exterior of each bag by an internal blast of air which enters via the venturi throat and is controlled by an electrically-operated solenoid valve. This type of collector is available in sizes ranging from about 500 to 5000 cu. ft minute and is said to have an efficiency of 99.9% when operating on a dust loading of 50 grains per cu. ft, with an ultimate particle size of 0.1 microns.

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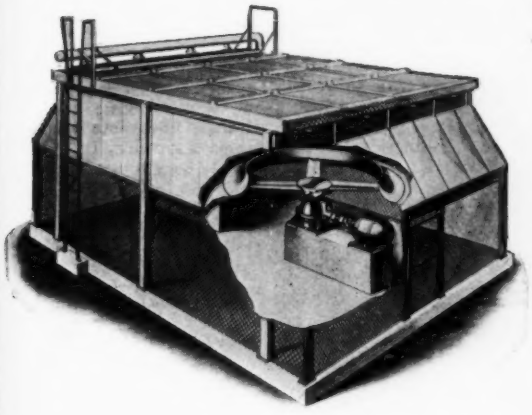

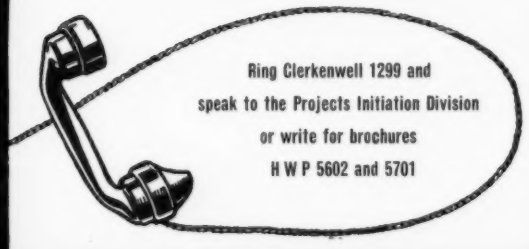

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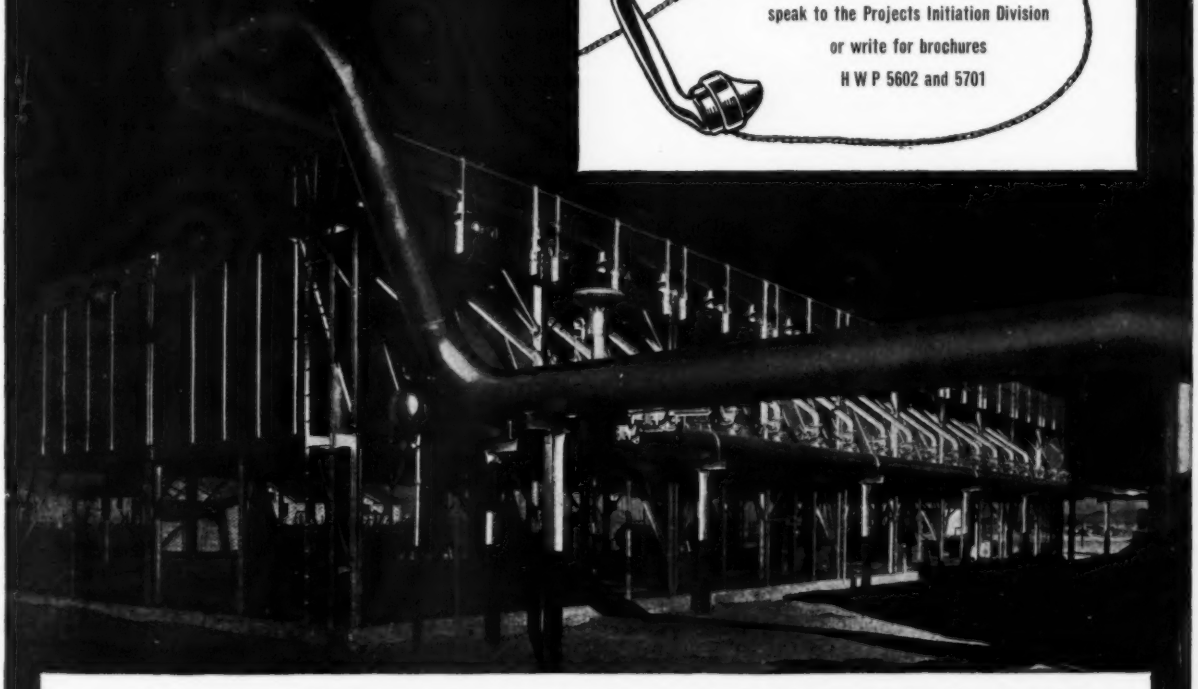

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P3294

HUMIDITY OF COMPRESSED AIR

by D. S. DAVIS

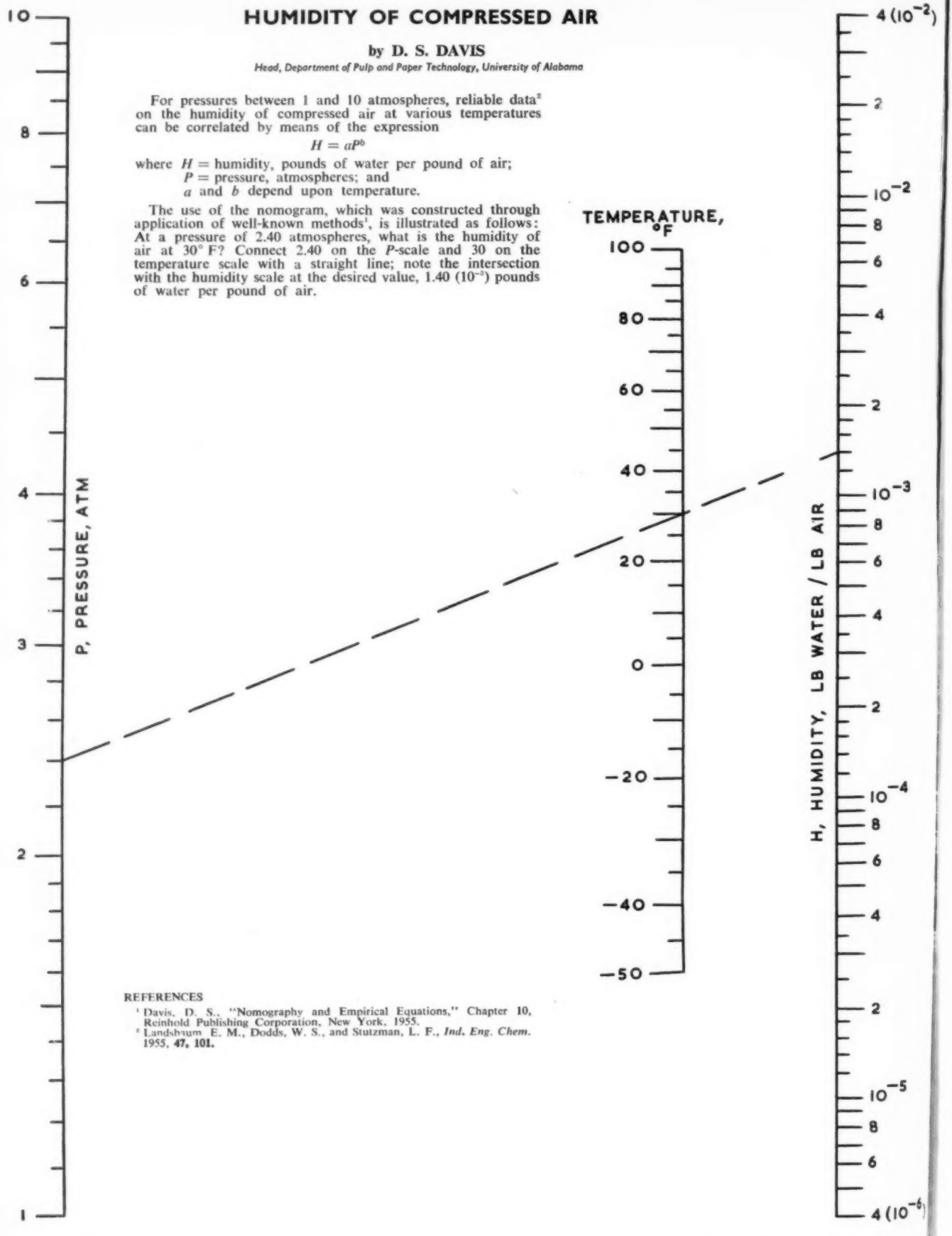
Head, Department of Pulp and Paper Technology, University of Alabama

For pressures between 1 and 10 atmospheres, reliable data[2] on the humidity of compressed air at various temperatures can be correlated by means of the expression

$$H = aP^b$$

where H = humidity, pounds of water per pound of air;
P = pressure, atmospheres; and
a and b depend upon temperature.

The use of the nomogram, which was constructed through application of well-known methods[1], is illustrated as follows: At a pressure of 2.40 atmospheres, what is the humidity of air at 30° F? Connect 2.40 on the P-scale and 30 on the temperature scale with a straight line; note the intersection with the humidity scale at the desired value, 1.40 (10^{-3}) pounds of water per pound of air.



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[1] Davis, D. S., "Nomography and Empirical Equations," Chapter 10, Reinhold Publishing Corporation, New York, 1955.
[2] Landsbaum, E. M., Dodds, W. S., and Stutzman, L. F., *Ind. Eng. Chem.* 1955, **47**, 101.

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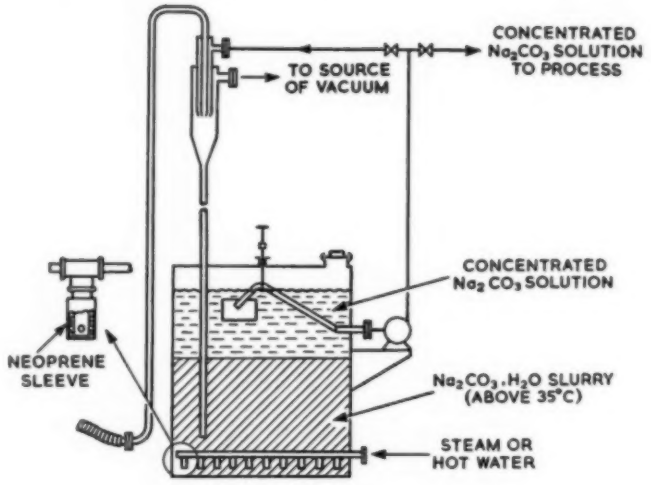
PROCESS ENGINEER'S NOTEBOOK

Storing Solids in Slurry Form Saves Space

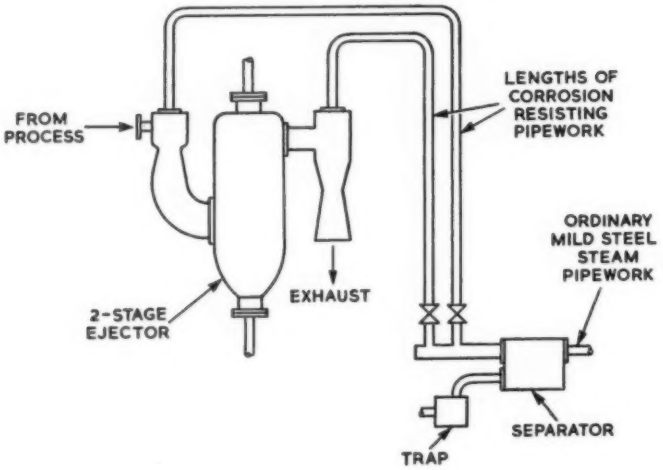


LARGE-SCALE users of soda ash solution can save storage space by storing this material in slurry form instead of as a powder. This is because sodium carbonate in the presence of its saturated solution will form a slurry of monohydrate crystals having a density much greater than that of dry soda ash. Whereas the density of the slurry will be approximately 105 lb. a cu. ft and will contain 59 lb. of carbonate, the dried powder will contain only 34 lb. of carbonate a cu. ft.

At one plant where the storage system is based upon this density advantage the slurry-producing device is combined with the pneumatic conveying system used for unloading solid soda ash from rail wagons. The combined slurry-making and separating apparatus comprises two concentric pipes fitted in the separator body. The saturated solution is pumped through annular space to mix intimately with the powder discharged from the inner pipe. The conveying air separates and passes to the vacuum system via a connection near the top of the vessel. Since the latter operates under vacuum, a leg of sufficient height has to be provided to allow the slurry to flow into the storage tank situated beneath it. In practice the slurry settles readily to the bottom of the tank leaving a layer of clear, saturated solution.

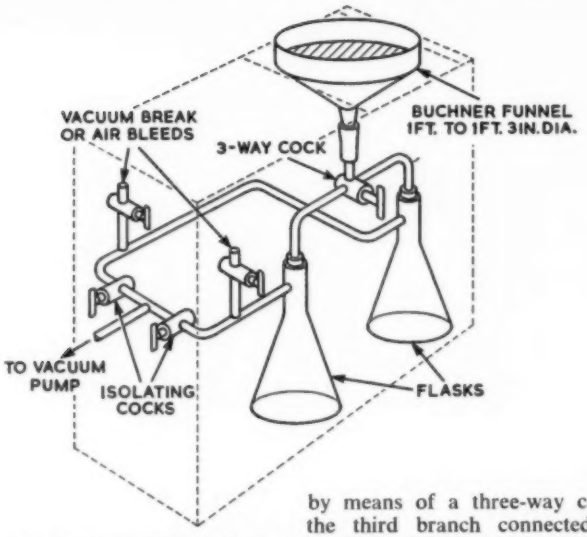
In the installation referred to above the respective depths of slurry and solution are 15 ft and 3 ft. Process requirements for carbonate solution are met by pumping from the clear solution layer. At the same time fresh water is added to the tank to replace the solution withdrawn. One precaution which must be carried out is the maintenance of a tank contents temperature above 35°C, since at this temperature monohydrate is converted to heptahydrate whose formation would result in the solidification of the contents. The additional water required for creating new solution and the steam required for maintaining the temperature are both introduced through a sparger system. It should be noted that the heat of solution and monohydrate conversion supply a useful proportion of the total heat required. The normal type of sparger cannot be used in this tank because the presence of solids would lead to blocking of the holes. Instead, a system of simple non-return valves is used which gives complete freedom from this trouble. These consist of short blanked tee branches drilled to allow a throughway for steam or water. Tightly-fitting neoprene sleeves are pushed over the tubes so as to seal off the holes when no fluid is passing into the vessel.

Corrosion Resistant Ejector Steam Connections



VACUUM PROCESSES involving corrosive chemicals make wide use of steam ejectors constructed from such materials as impervious carbon or stoneware for the source of vacuum. This usually gives a successful vacuum-making system, provided the connecting pipework for the steam supply to the ejectors remains free from corrosion. Mild-steel pipework is not always satisfactory for the final connections to the ejector and a better arrangement is to terminate the mild-steel pipework some feet from the ejector and to make the final connections in tubing made from a resistant material such as stainless steel or copper.

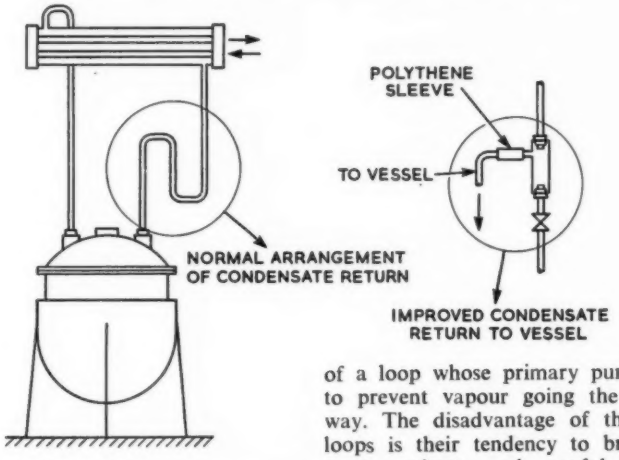
Improved Small-scale Filtrations



IN SMALL pilot-plant work large Buchner funnels are frequently used for vacuum filtration. The usual practice is to connect the funnel to a large flask, which is connected to the vacuum pump and acts as a receiver. This system has its disadvantages, especially when cake cracking is to be avoided and when large volumes of filtrate or washing liquor are to be handled. A convenient and inexpensive solution to this problem is to employ two receivers interconnected by means of a three-way cock with the third branch connected to the Buchner funnel. This arrangement allows the filtrate to be directed into either flask without disturbing the vacuum and thus avoids cake cracking. This arrangement is particularly useful when precoating is necessary or when filtrate and wash must be separated. The entire apparatus may be very conveniently assembled within a slotted angle frame, with the valves mounted on a small panel for ease of operation.

M. C. REECE

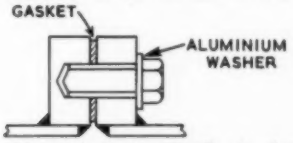
Reflux Return on Batch Reactors



A COMMON PRACTICE in organic pilot-plant preparations carried out in the presence of solvents is to conduct the reactions under reflux for a given period. If corrosive materials are handled in the apparatus, glass condensers may be used in conjunction with glass pipework. The condensate is returned to the vessel by means of a loop whose primary purpose is to prevent vapour going the wrong way. The disadvantage of the glass loops is their tendency to break. A more robust and useful return arrangement can be made from a tee branch—this has the additional advantage of allowing a drainage connection to be fitted. When it is desired to withdraw solvent from the vessel or to concentrate the product, the solvent can be diverted through this valve. (Courtesy: Allen & Hanburys Ltd., Ware, Herts.)

Preventing Seepage at Bolt Holes

FLANGED JOINTS employing full-face joints on vessels or process pipelines sometimes prove troublesome through leakage of material through the bolt holes. This often leads to a messy appearance at the joints and interferes



with "good-housekeeping". A simple remedy is to fit washers of soft metal to seal off the bolt holes from the surroundings. The washers may be cut from scrap 18-g. aluminium. An alternative is to use scrap gasket material backed by hard metal washers at the bolt head.

Sprayed Gaskets

DUCTILE GASKET MATERIALS for low temperatures are limited to Fluon, Hostaflon or combinations of these materials with asbestos fibre. Soft metallic gaskets have the disadvantage even when used in tongue and groove-type joints of requiring high sealing pressures. An alternative is to employ a layer of aluminium deposited by means of an inert-gas spraygun. One of the jointing surfaces should have two concentric ridges machined upon it on either side of the bolt circle and clearing the bolt hole. The other joint circle, which is the one upon which the aluminium is sprayed, is machined plain. It is lightly sand-blasted and, after spraying, is rubbed down gently with emery cloth to remove peaks. In making the joint a bolting-up sequence has to be followed.

Contributions invited

THE EDITOR invites readers to submit, for possible publication in "Process Engineer's Notebook", notes on practical devices that have been elaborated on the job for improving the operation or increasing the safety of processes, or that have been extemporised in special circumstances. The contributions preferably should be of about 250-500 words, and be illustrated with a line diagram or sketch, or a photograph. A minimum of three guineas will be paid for each contribution used. They will be published anonymously or under the contributor's name, according to his wishes.

World of Chemicals

Enzyme from Pineapple

A new proteolytic enzyme product called bromelain is being produced commercially from the lower stem of the pineapple plant by the Dole Hawaiian Pineapple Co. The product is in fact a mixture of several enzymes, including acid phosphatase, amylase and peroxidase. Bromelain is the third enzyme product to be derived from the pineapple, and the particular part of the plant from which it is derived, the "mother stump", has been regarded hitherto as a waste product. The extraction process consists of washing and crushing the stems and extracting the juice. Bromelain is precipitated from the clarified juice by the addition of acetone. It is then separated by centrifuging, and is oven dried.

Continental Refineries

The capacity of B.P. refineries at Antwerp and Hamburg has been increased by 1,500,000 tons of crude oil a year, following the completion of modifications to distillation plant and auxiliary equipment. The annual capacity of the Antwerp refinery is now 4 million tons. New plant at the Hamburg refinery includes a hydrogen refiner having a capacity of 6500 barrels of gas oil a day. Associated with the plant is a sulphur-recovery plant which produces about 10 tons of sulphur daily. A hydrogen refiner of 400,000 tons a year capacity and a catalytic reformer of 350,000 tons annual capacity will be commissioned next year at the Antwerp refinery.

Oslo Refinery

A/S Esso-raffineriet, Norge, is the name of the new Standard Oil subsidiary which is to build Scandinavia's biggest oil refinery—on the eastern side of the Oslo Fjord. The plant will have a capacity of 40,000 barrels daily. Construction work is due to start next April, and the refinery is expected to be ready for commissioning in the following spring. The installation is expected to cost Kr. 215 million (£10.75 million), about 40% of which will be borrowed in Norway.

Uruguayan Refinery

An extension programme to more than double the capacity of the refinery of the Administration Nacional de Combustibles Alcohol y Portland (ANCAP), Montevideo, has been decided upon. Five new plants, of Kellogg design, are to be added. They are: a 28,000 atmospheric and 10,000 vacuum unit, a 5000 bpd (fresh feed) orthoflow fluid catalytic cracking unit, a 3000 bpd catalytic reforming unit, a gasolene stabilisation gas-recovery unit, and a 4500 bpd gasolene-treating unit. The main products will include high-octane gasolene, fuel oil, liquid petroleum gas, kerosene, diesel oil and asphalt.

New Insecticides

Four new systemic insecticides were described at the Fourth International Crop Protection Congress held recently in Hamburg. Two of the products, phosphorus compounds, are rapidly broken down within the plant to form, it is claimed, harmless residues. They are Phosphamidon, developed by Ciba, and Phosdrin, a vinyl phosphate developed by Shell. The other products are Thiodan, a chlorinated sulphur compound, and Hoe 2705, a polychlorinated hydrocarbon, both made by Hoeschst.

Australian Gas-handling Plant

At the Kwinana Western Australia refinery of B.P. a new bottling and bulk-filling plant for liquid petroleum gas, designed by the refinery's staff, was commissioned recently. Most of the plant which has a storage capacity of 54,000 lb. of liquid gas, was constructed from materials of Western Australian manufacture.

Canadian Energy Policy

The Canadian Prime Minister has announced the establishment of a six-man Royal Commission to make recommendations for a natural energy policy for the Dominion. The commission has been asked, in particular, to consider whether any special measure need be taken in relation to the Trans-Canada pipe-lines to safeguard the interests of Canadian producers or consumers.

Plastics Production in India

The production of polystyrene in India, commenced in May this year, has reached a level of 1 million lb. annually. Two schemes for the manufacture in the country of polyethylene using alcohol as raw material have been sanctioned. The factories, which will be in Calcutta and Bombay, will have a total capacity of 5100 tons a year.

Scope for New Plant

Irmaos Iochpe S.A., Brazil, have announced that they wish to start manufacture, on a fairly large scale, of fertilisers composed of ammonium sulphate, triple superphosphate and potassium chloride, in granulated form. The company say that they are not in a position to finance the venture themselves, on account of the high cost of the machinery involved, but would welcome the participation of a United Kingdom firm, directly or indirectly.

French Natural Gas

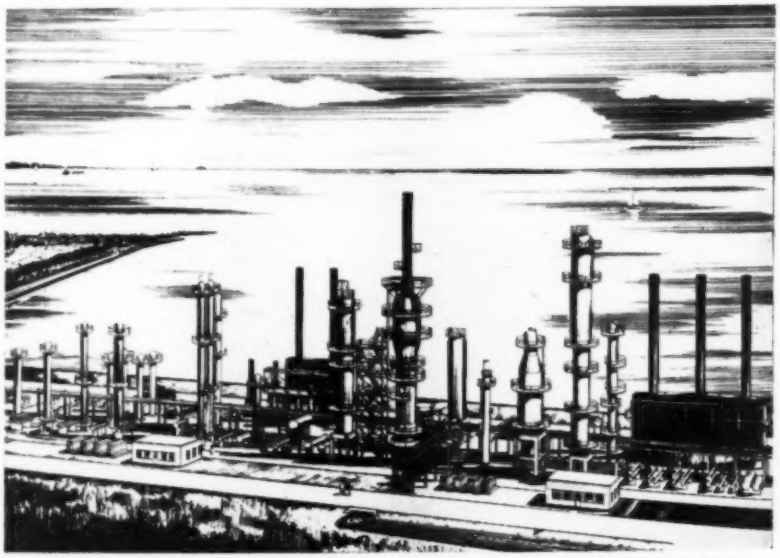
Production of natural gas from the Lacq deposits is progressing satisfactorily and has reached 12 million cu. m. of gas with, in addition, 3500 tons of sulphur monthly. It was estimated recently that French consumption of gas will rise in the next ten years from 6000 million to 15,500 million cu. m.

Sugar Production in Turkey

A committee has been appointed to investigate the possibility of building a sugar refinery at Adana, Turkey, which would use both beet and sugar-cane. Output on the basis of the estimated harvest for 1957 would be 370,000 tons of sugar annually.

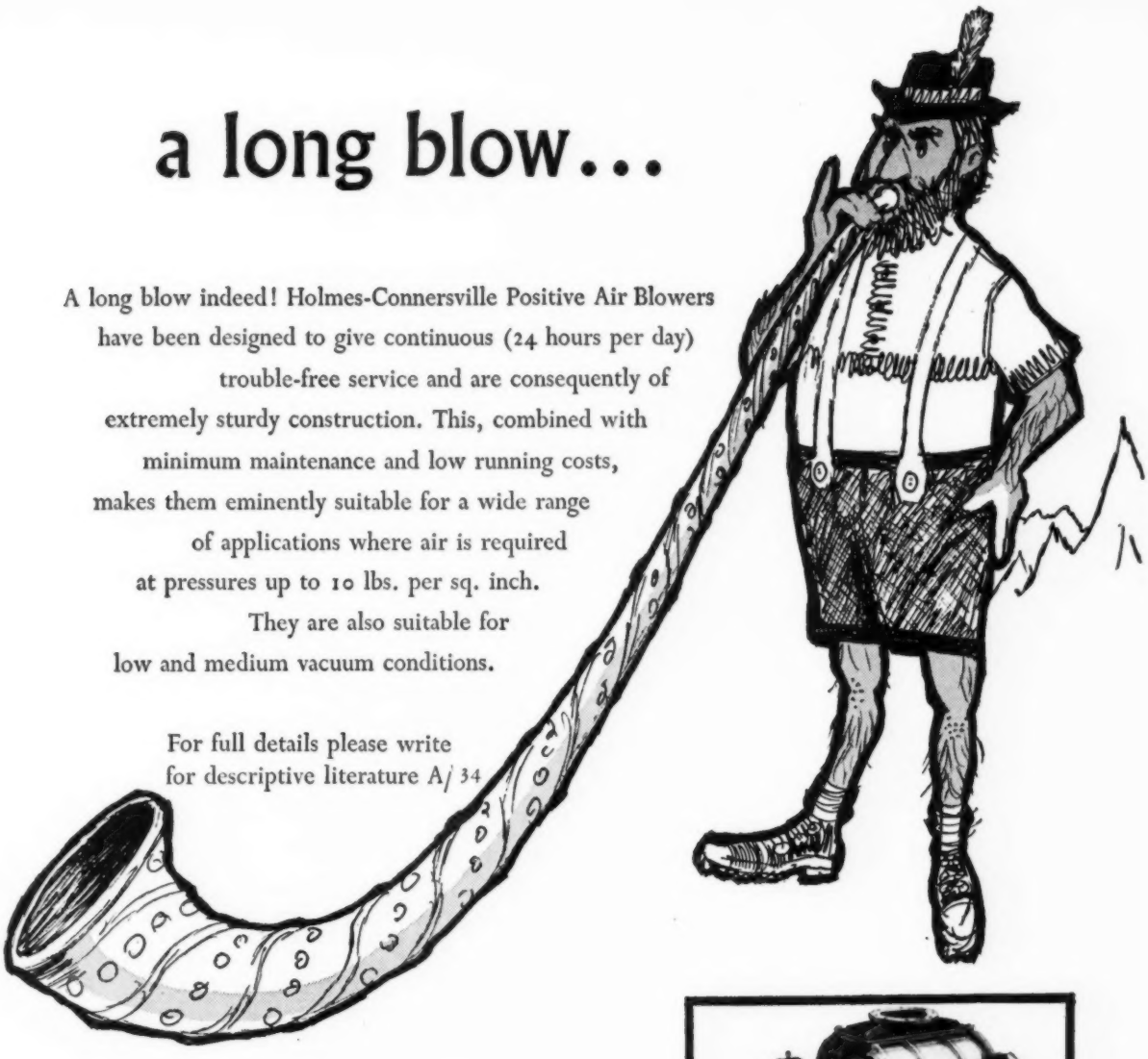
Tanganyika Niobium Ore

A new pyrochlore mine in the Southern Highlands of Tanganyika was opened by the Secretary of State for the Colonies (Mr. Alan Lennox-Boyd) recently. It is being operated jointly by the Mbeya Exploration Co., a Dutch enterprise, and the Colonial Development Corporation.



New facilities planned for the ANCAP La Teja Refinery, Uruguay. Atmospheric and vacuum unit on the right, orthoflow fluid catalytic cracker with stabilisation and reforming units centre, gas recovery and treating units left. Note that the plot is laid out in a typical in-line arrangement minimising maintenance problems, pipe runs and simplifying operation.

a long blow...



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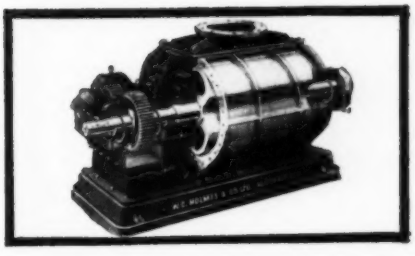

A cut-away view of an HI Type Blower

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Book Reviews

Chemical Engineering Practice—Volume III: Solid Systems

Edited by H. W. Cremer and Trefor Davies

Butterworths Scientific Publications, London, 1957, 534 pp., 95s.

LAST year the profession accorded an enthusiastic reception to Volumes I and II of this twelve-volume treatise on chemical engineering practice (*British Chemical Engineering*, September, 1956, page 286), and reviews have shown that the editors' expectation, as mentioned in the preface, that the manner of presentation might not arouse general agreement, has been only slightly justified.

Volume III covers solid systems which are related to handling operations, such as size reduction, screening, classification, mixing, storing, conveying and gas:solid separation. It constitutes the most coherent volume of the series so far. The collection of this material in one volume is indeed unique in encyclopædic literature, as the following comparison with two similar and up-to-date encyclopædia shows. The German "Ullmann's Encyklopädie der Technischen Chemie" contains only about one-fifth of this material in a volume on process engineering, and the American "Encyclopædia of Chemical Technology" (Kirk, R. E., and Othmer, D. F.) contains only about one-eighth of it, spread over five volumes.

The professional standard of the contributions is invariably high, as the authors are either industrial experts or are directing research in the subjects on which they write. Since the treatise was designed to have a chemical *engineering* approach, one could wish for a stronger editorial policy to unify much of the theory on the motion of particles past fluids, or the process engineering aspects. On the other hand, one cannot help wondering whether the authors have not been deliberately allowed to include material as it suited them, so as to make their chapter or chapters as far as possible self-sufficient and thereby to facilitate a quick understanding by the design or development engineer.

It was noted that Stokes' equation appears on three occasions in identical form, but with different symbols. One is a little perplexed to find the critical Reynolds number before departure from streamline flow to be given correctly as 0.2 on page 30 but as 2.0 on page 255.

The excellency of production of previous volumes has been maintained and there are again numerous clear illustrations and several plates.

P. EISENKLAM

A History of Industrial Chemistry

by F. Sherwood Taylor

Heinemann, London, 1957, 467 pp., 30s.

THIS book needs no recommendation to chemists. It is the posthumously published work of Dr. F. Sherwood Taylor, sometime Curator of the Museum of the History of Science, Oxford, and later, at his death, Director of the Science Museum, London. An author well known to chemists and to general readers alike for his remarkable powers of exposition and his masterly command of a fluent prose style, Taylor, originally a classical scholar, had an absorbing interest in chemistry and in every phase of that science; and his book on the history of industrial chemistry, on which he had long been engaged, was eagerly awaited by all who knew his work. It has been seen through the press by Mr. F. Greenaway, a member of the staff of the Science Museum, who deserves thanks for the loyal and able discharge of his regrettable task.

Taylor divided his history into two parts after having defined industrial chemistry in the broadest terms; namely, as including "all modifications of the composition of matter that have been undertaken for profit or use, even though they may not in earlier times have been recognised as belonging to chemistry nor yet have been carried out on what we today regard as an industrial scale". The first part, amounting to one-third of the book—itself a comment on the antiquity of the subject—deals with the prescientific chemical industries, which, of course, brings the history to 1800 or thereabouts. And here we have a period of many centuries during which the successes of the chemical industry were based on empirical knowledge, such as was embodied in the "craft" or "mystery", and during which the main chemical industries were those concerned with metals and alloys, cements and mortars, ceramics, glass, pigments, acids, fuels, dyes, soaps, medicines, sugar and alcohol and its products.

In the second period, a mere century and a half to our own time, modern industrial chemistry arose with its so-called "artificials" or "synthetics" (both very unsatisfactory names): and in this second part of the book we see industrial chemistry passing from craft to science with the development of the great acid and alkali industries, of bleaching, of the use of non-ferrous metals, of new illuminants, of the great variety of organic products, of synthetic dyes and drugs, of new explosives and detergents, of plastics, and so on to the very newest industry of atomic energy.

The book is fully documented for the benefit of those who wish to refer to original sources and it is splendidly illustrated. It gives within reasonable compass a fascinating picture of what chemistry has contributed to civilisation through the long centuries from the earliest ages when man first tried to control his environment, and of the predominant part that it plays in our modern world.

D. MCKIE.

SHORTER NOTICES

The Reduction and Presentation of Experimental Results

by J. T. Richardson, B.S. 2846: 1957, 43 pp., 10s.

THIS IS one of the small group of British Standards devoted to methodology rather than definition of material products. It gives a concise statement of accepted procedures in this field for use in science and technology, but wisely refers the reader to text-books for a wider knowledge of the subject. It is, nevertheless, a masterpiece of compression giving guidance on presenting frequency distributions and on setting out confidence limits for estimates of means and standard deviations.

Filler Rods and Wires for Gas Welding

B.S. 1453: 1957, 25 pp., 6s.

Filler Rods and Wires for Inert-Gas Arc Welding, Part I

B.S. 2901: Part 1: 1957, 30 pp. 6s.

THESE BRITISH STANDARDS have been prepared as parts of a comprehensive range of standards covering filler rods and wires. They are presented in a generally uniform format, opening with a section on general requirements and continuing with specific requirements uniformly grouped under the same subdivision headings in the respective standards. For example, those grouped under "A" comprise steel filler rods and wires, Group "C" copper and copper-alloy, Group "G" aluminium and aluminium alloy.

Manhole and Inspection Openings for Chemical Plant

B.S. 470: 1957, 3s.

THIS BRITISH STANDARD covers manhole, handhole and inspection-hole openings in chemical plant and in mobile tanks for chemicals, but does not apply to steam generating plant. The specification lists only types and dimensions; the number and positions of the various openings are given in other Standards (the reference numbers for which are quoted) dealing with specific types of plant.

Comprehensive Inorganic Chemistry— Vol. 6 "The Alkali Metals", by J. F. Suttle: "Hydrogen and its Isotopes", by Robert C. Brasted

D. Van Nostrand Co. Ltd., London, 1957, 234 pp., 45s.

THESE TWO-BOOKS-IN-ONE form part of an eleven-volume reference work on the chemical elements and their inorganic compounds. Their purpose is to serve as a ready reference for those engaged in chemical manufacture and development and those in advanced studies in chemistry. Emphasis has been placed on chemical properties and relationships and their interpretation in terms of theoretical concepts of atomic and molecular structure.

Reactions of Organic Compounds

by Wilfred John Hickinbottom

Longmans, Green & Co. Ltd., London, 1957, 608 pp., 45s.

THIS THIRD EDITION of Hickinbottom's text on the organic compounds has been largely rewritten in the light of present knowledge. Much new material has been introduced, particularly concerning the use of new techniques and new reagents for reduction, oxidation and condensation. The general theme of the book is to present the facts of organic chemistry in terms of the reactions of typical groups essentially from the point of view of laboratory practice.

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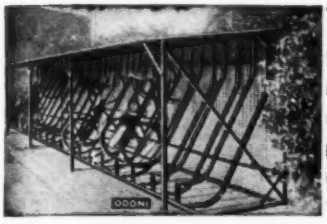

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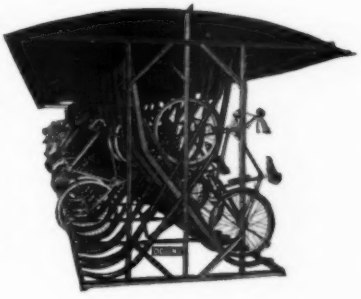

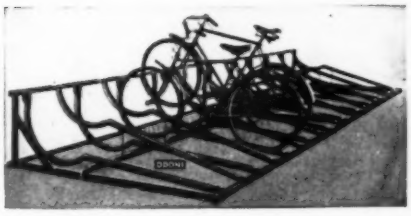

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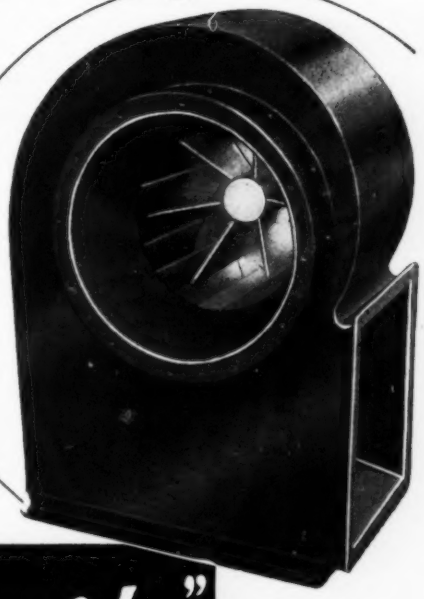

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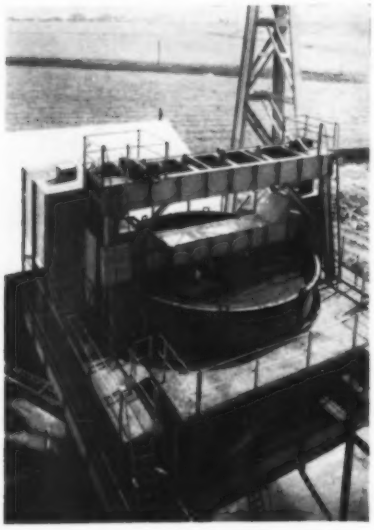
PLANT EQUIPMENT NEWS

Oxide Discharger

A machine for discharging oxide—a job previously done by hand—is being made by Newton, Chambers to their own patented design. In its operation, a series of steel curved ploughs, working on a revolving turn-table, cut the fouled oxide and propel it towards a central discharge opening in the oxide container. The containers are fitted with a removable centre tube, which, when the containers are in position in a tower, conveys the gas into or away from the tower. Removal of the tube makes the central opening within the oxide mass. The cutting mechanism is carried on a gantry. The process of emptying the container is as follows. First the container is removed by a crane and lifting frame from the tower where it is stored, and it is lowered into position on the turn-table. The crane then removes the centre tube, and the gantry and cutter



beam are positioned over the container. The turn-table is set in motion, the beam descends at a constant speed, and the oxide is discharged in a time which can vary between 25 and 40 minutes. The cutter beam is lifted, the container swept free from oxide, and transferred to the filling turn-table where it is recharged with oxide. The makers say that a mechanical discharger can be built into any make of oxide-handling plant to add moisture and alkali or for other forms of oxide treatment which may be necessary. **Newton, Chambers & Co. Ltd., Thorncliffe, near Sheffield.**

BCE 2280 for further information

Frequency Measurers

New to Great Britain, except for use by the G.P.O. and the B.B.C., is a range of electronic frequency measuring instruments by Schomandl, Munich. The instruments, which are said to be unique, have applications in chemical plant and are now being made generally available in Britain by Solartron, as their sales and service agent. The instruments are designed to produce precisely any desired frequency from a few tens of cycles to 30,000 megacycles and more. An application, which has reached the prototype stage in Germany, is a revolving-disc viscometer for the continuous measurement of viscosity, the instruments being used to control the speed of rotation. The continuous detection of certain components of petroleum, and, eventually, their measurement are uses which can be developed, it is said. In the chemical research field the instruments are expected to have important applications in developing micro-wave and radio-frequency spectroscopy, and nuclear magnetic resonance for the analysis of molecules. The new equipment includes the following instruments: the standard frequency generating and measuring decade, type ND5; VHF-service-frequency meter, type FD1; multi-pen frequency drift recorder, type NFR2; standard frequency decade for microwaves, type FD3. Solartron state that it is their policy to act as agents for foreign equipment only when the products are unique, and therefore not available from British sources. **The Solartron Electronic Group Ltd., Thames Ditton, Surrey.**

BCE 2281 for further information

Cathodic Protection

Two new series of anodes for cathodic protection of plant are being made available by F. A. Hughes after several years' development work. The Guardalloy anodes, Nos. 696 and 855, are made of precious metal, are small, and they operate economically at current densities which would not be attractive with other materials. Their use involves virtually no interference to hydraulic flow, the makers say. The electrodes are designed for use for the internal protection of vessels, heat exchangers and pipelines large and small, etc., with practically no limitations of electrolytes. They have been used with success in plant handling potable and process waters which must be guarded against any contamination. Laboratory and field tests with the company's new Guardion silicon-iron anode indicate that a performance equivalent to a minimum charge of 10,000 amp. hours a pound can be expected of this material when working at current densities of up to 10 amp. a sq. ft. Three standard models of the anode are available. The company is also introducing a new soil resistivity meter suitable for spot measurements, and a new Guardion corrosion voltmeter. **F. A. Hughes & Co. Ltd., Devonshire House, London, W.1.**

BCE 2282 for further information

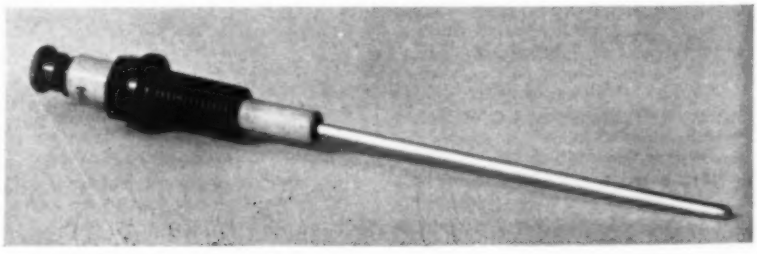
Separating Plant

Pegson have recently been granted the exclusive manufacturing rights in the British Isles for the U.S. Ore & Chemical Corporation's heavy-media separating vessel. Production arrangements are now under way. Feed is introduced to the vessel at the surface level of the medium. Float material travels across the vessel and discharges over the float overflow weir. Sink material drops to the bottom of the vessel and is removed by an oscillating rake which alternately carries "sink" to the discharge lips at each end of the vessel. Simplicity has been one of the chief aims in the plant's design. **Pegson Ltd., Coalville, Leicester.**

BCE 2283 for further information

Self-induced Spray Collector

After an extensive study, Dallow, Lambert have produced a new range, series MG, of self-induced spray-type wet dedusters. They are available in 13 standard sizes ranging from 2000 cfm to 48,000 cfm capacity. The deduster has been tested searchingly in the company's laboratories and has undergone trials on sites. It is available with the following methods of sludge removal: type A—mechanical sludge clearance; type B—



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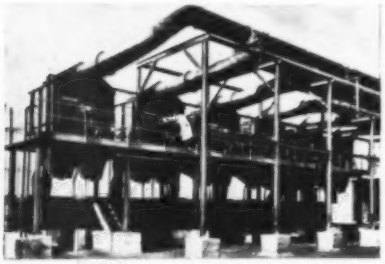
PLANT EQUIPMENT NEWS



discharge through quick-release doors into mobile containers; type C—manual clearance; and type D—discharge through drain valves. **Dallow, Lambert & Co. Ltd., Spalding Street, Leicester.**

BCE 2284 for further information

Valves in Titanium

Among the small titanium castings now being made as the result of a research and development programme being undertaken by the Metals Division of I.C.I. are Saunders valves, type A, 1 in. They are being manufactured as prototypes for plant trials. Other chemical plant components, such as impellers and nozzles, are to follow. **Imperial Chemical Industries Ltd., I.C. House, Millbank, S.W.1. Saunders Valve Co. Ltd., Cwmbran, Mon.**

BCE 2285 for further information

New Stainless Steel

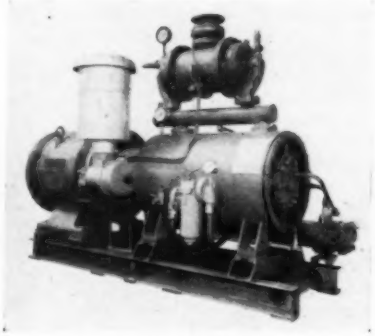
Firth-Vickers stainless steel 520, under development since 1953, is now being made on a full production basis. It is weldable and combines high-tensile strength and resistance to corrosion equivalent to that of 18/8 steels. It is available in the form of bar, castings, forgings, sheet and strip. Other characteristics claimed for the steel include high resistance to fatigue and stress-corrosion cracking; a relatively low thermal expansion (equivalent to that of mild steel) and high resistance to notched impact loads at sub-zero temperatures. The ceiling temperature for service is 500°C. A typical composition of the steel, the makers say, is as follows: carbon 0.07%, chromium 16%, nickel 6% copper 1.5%, molybdenum 1.5% and titanium 0.3%. In tests on corrosion resistance, cylinders of the steel immersed for one year in a 3% sodium chloride solution at room temperature were practically unaffected, whereas under similar conditions 13% chromium-steel F.I. suffered severe wastage by corrosion in one month and S.80 steel was badly attacked in six months. Laboratory acid tests over wide ranges of concentration and temperature rate have shown, the makers say, F.V. 520 to be equal to 18/8 steels. In resistance to stress corrosion cracking it can be superior to these steels, it is said, e.g., in tests with high-pressure steam at 300°C under chloride or caustic contamination.

The steel is said to be readily welded without pre-heat. Heat-treatment after welding is not essential but, for stress relief, it may be desirable to heat the fabrication after welding and to apply a post-weld heat-treatment at 550°C. Bars and forgings are usually supplied in the fully heat-treated condition. Strip coils in 16-28 gauge are produced up to 1 metre wide in the AC 1050°C condition, suitable for a number of forming operations. Although in this condition the steel has a 0.1% proof stress not greater than 25 tons/sq. in., it work-hardens rapidly. Formed components may be hardened fairly uniformly across cold-worked and non-cold-worked parts by relatively low-temperature heat-treatment cycles. **Firth-Vickers Stainless Steels Ltd., Staybrite Works, Sheffield, 9.**

BCE 2286 for further information

Rotary Compressor

A special feature of the new Worthington-Simpson oil-cooled sliding-vane rotary compressors is that they are designed for the employment of large quantities of oil to ensure complete lubrication of working parts and to form an effective seal against air leakage between the sliding vanes of the rotor. The oil also acts as an internal coolant absorbing a high proportion of the heat of compression so that the final air temperature is below 200°. There is no carbon formation and no necessity for after-coolers in most applications, the makers say. Special attention has



been given to the efficiency of the oil separator. The oil cooler comprises a water-cooled tubular heat-exchanger. **Worthington-Simpson Ltd., Newark-on-Trent, Notts.**

BCE 2287 for further information

Gas Refrigerating Machine

A new version of the Philips refrigerating machine is now available. Known as the P.W. 7000, it is an electrically-driven single-cylinder unit, capable of producing 5 l. of liquid air or liquid nitrogen an hour within 15 minutes of starting up. The gas to be liquefied is not compressed or passed through any working parts—a design feature, the makers say, which helps to assure a very high quality of product. The machine will produce liquid gas from gases which liquefy at above −200°C, and temperatures of from −80°C to −200°C can be reached in a single stage. Under normal conditions the machine requires only one hour for defrosting and draining of the freezer after 16 to 20 hours' production. Moisture and carbon dioxide are removed simply by freezing. The machine is compact and operates automatically after starting up. **Philips Electrical Ltd., Shaftesbury Avenue, London, W.C.2.**

BCE 2288 for further information

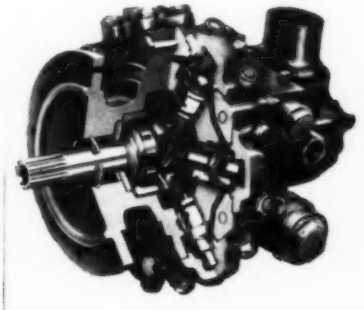
Strippable Coating

Rhino Hide is a strippable plastic coating which is being supplied by Croda as a solution suitable for spray application. The material forms a tough, elastic, waterproof and chemical-resistant skin on many metal surfaces. In its standard form it is grey liquid, but it can be supplied in other colours, or transparent. The product will form coatings of thickness 0.001-0.040 in. **Croda Ltd., Snaith, Goole, Yorks.**

BCE 2289 for further information

Hydraulic Pump

Dowty are producing a new industrial version of their Vardel hydraulic pump. It is a two-stage, self-regulating, high-pressure pump based on a design used for many years in aircraft engineering. A first-stage, low-pressure gear pump, a second-stage piston pump and an unloader gear are the essential parts of the equipment. It is available for pressures of 1000-4000 psi, with outputs of 2½-5 gpm and speeds of 1500-3000 rpm. The pump incorporates its own cut-out and



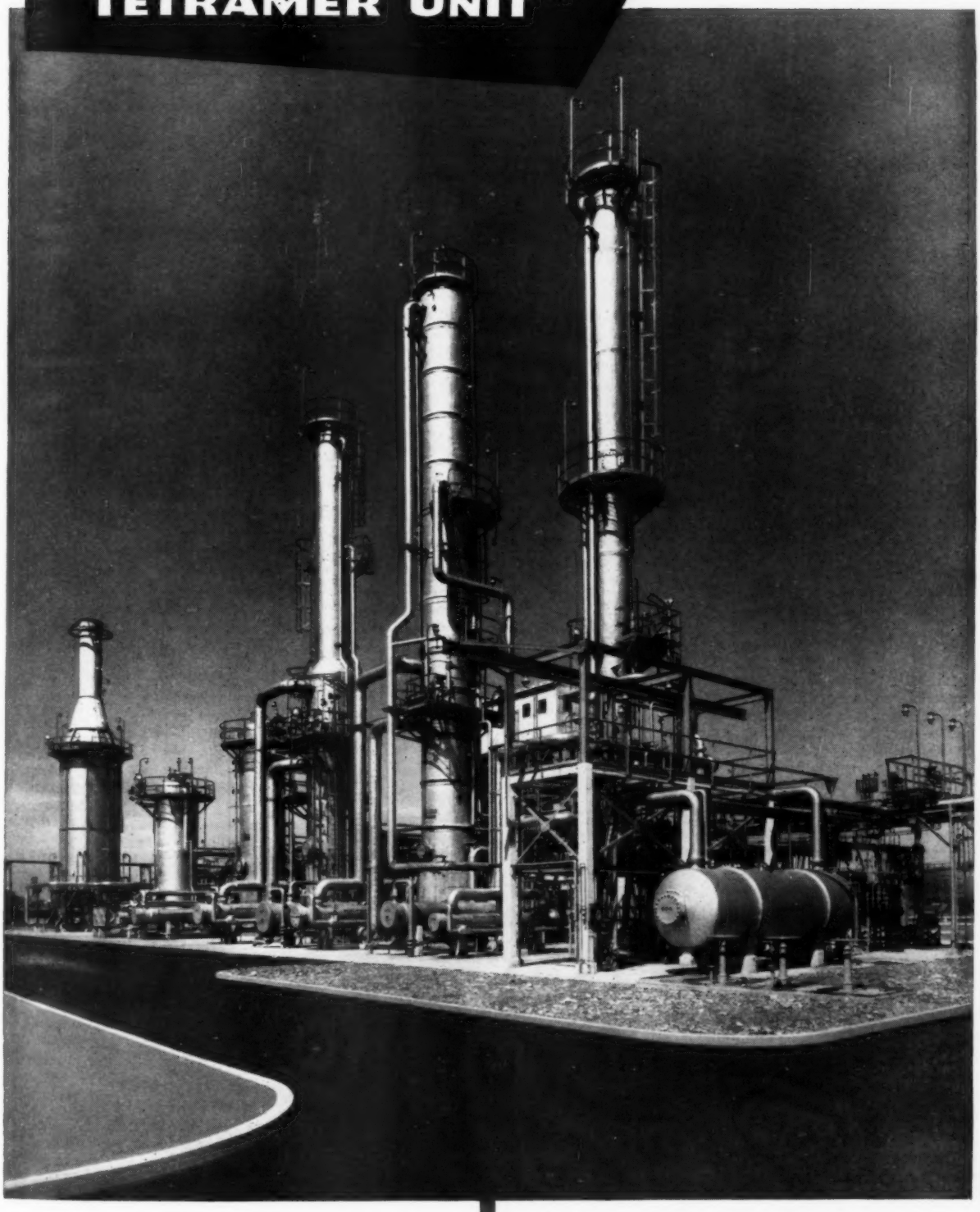
relief valves. At 3000 rpm off-load a pressure of 4000 psi is maintained by the pump with a power input of under 2 hp. Flick pressures caused by a sudden cessation of delivery when an actuator comes to the end of its stroke has been virtually eliminated, the makers say. **Dowty Equipment Ltd., Cheltenham.**

BCE 2290 for further information

Diaphragm Valves

A new range of diaphragm valves, introduced by Warren, Morrison, is designed for handling non-corrosive liquids and gases for which the company's pinch valve might prove too expensive, and very corrosive fluids. PTFE diaphragms and rigid PVC bodies are available in addition to the normal

TETRAMER UNIT *



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PLANT EQUIPMENT NEWS

range of lined metal bodies and synthetic rubber diaphragms. A rising-spindle type of position indicator is a standard fitting enabling the position of the valve to be seen at a glance. Tight closure against high pressure with no danger of passing is ensured, it is claimed, by the circular form of the valve seat. The specially-formed seat also reduces diaphragm flexings to a minimum. **Warren, Morrison Ltd., 29 Bury Street, London, S.W.1.**

BCE 2291 for further information

Fibre-plastic Tanks

After considerable experimental work with glass fibre-plastic materials as materials of construction for chemical plant, Precolor are at present making tanks for the electro-plating and the textile industries, and are undertaking the construction of tanks to contain mineral and oleic acids. The largest tank so far made is 24 ft × 10 ft × 3 ft 4 in, fabricated in two sections. **Precolor Ltd., Wolverhampton.**

BCE 2292 for further information

Indicating Thermostat and Switch

A.R.I.C. are making available a new indicating thermostat designed specially for industrial processes. It can be supplied for various ranges of temperature from −100°F to +500°F, and it is fitted with a micro-switch rated at 10 amps. at 250 V A.C. or 440 V A.C. The instrument is housed in a diecast aluminium case, finished stove-enamelled hammered blue-grey, with a half-glazed lid exposing the legible segmental indicating and setting dial. The company is also supplying a new type of indicating pressure switch available for pressure ranges from 0 to 50 psi up to 0 to 4000 psi. **The Accurate Recording Instrument Co., Garth Road, Morden, Surrey.**

BCE 2293 for further information

Isotope Level Detector

Although the I.D.L. level detector, type No. 890, is designed for checking the level of liquid carbon dioxide in fire extinguishers, it is suitable for any application where a rapid check is required on the content of closed cylinders or pipes of up to 10 in. in diameter. Inspection can be carried out without dismantling the vessel, and the measuring head is so designed that cylinders can be inspected even when only 1 in. apart, and in rows three deep provided that the spacing between rows is not less than 1¼ in. Other applications include the location of blockages involving a liquid-gas interface in pipelines and the indication of the presence or absence of liquid or granular material in chemical plant. The instrument consists of a yoke and an indicator unit, connected by a cable. One arm of the yoke carries a small radioactive source and the other holds a detector unit incorporating a Geiger-Müller tube. The yoke is held so that it spans the vessel under inspection. When it is moved along the length of the vessel, any interface affects the amount of radiation reaching the detector, and the reading on the meter in the indicator unit changes. The yoke is adjustable to suit different diameters. The instrument operates either from a standard mains supply or from the 6-volt battery that may be provided. There is no danger to the health of the operator. The design of the instrument is based on joint research with Walter Kidde. **Isotope Developments Ltd., Beenham Grange, Aldermaston Wharf, near Reading, Berks.**

BCE 2294 for further information

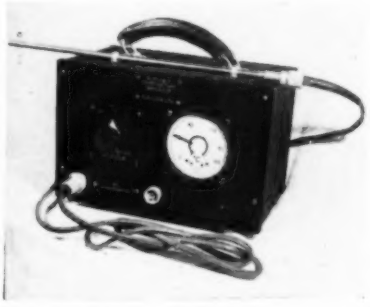
Differential Pressure Meter

Sunvic are to manufacture under licence in the United Kingdom the differential pressure meter developed by Barton Instruments of California. Using two mechanically-linked, liquid-filled bellows, the instrument operates on the rotation of a torque tube which corresponds to changes in applied differential pressure. The torque arm can be coupled to a pressure transmitter to provide an output of 3-15 psi. It can also be linked mechanically to an indicating gauge or recorder. The instrument may be supplied with a body of either cast or stainless steel, pressure-rated to 2500 psi. The differential overload rating is the same as the static pressure rating. Selection of a low-freezing-point liquid for the bellows filling allows the instrument to be used in temperatures down to −25°F; recommended maximum temperature for continuous duty however, is 200°F. Standard differential pressure ranges are from 0-20 in. w.g. up to 0-200 in. w.g. The range spring is located outside the bellows assembly and is simple to alter. An internal, adjustable pulsation dampener is fitted. The bellows and range spring assemblies are of stainless steel and, the makers say, liquid seals are not necessary when handling corrosive liquids. **Sunvic Controls Ltd., 10 Essex Street, London, W.C.2.**

BCE 2295 for further information

Temperature Indicators

Locks have introduced two new resistance-thermometer temperature indicators. The mains-operated model, type MT1, is suitable for use in the temperature range −200°C to +500°C in minimum spans of 100°C. Single point, multi-point (up to 50 way) and multi-channel (up to 25 indicators from one power unit) are available. The standard meter indicator has a clearly-marked scale 5.65 in. in length. The temperature-



sensitive element is a Weston resistance thermometer which is interchangeable and can be mounted remotely from the indicator. It is made of platinum wire wound into a helix, forming the resistance element which occupies a length of approximately ⅜ in. at the top of a stainless-steel tube, having an outside diameter of ¼ in. The claimed accuracy is better than 0.5%. The portable instrument, model PT1, is suitable for a similar temperature range, the standard instruments being made for the ranges 0-100°C and 0-150°C. The instrument is easily portable the makers say. It has self-contained long-life batteries and a selector switch which allows the use of two thermometers on the one instrument. **A. M. Lock & Co. Ltd., 79 Union Street, Oldham, Lancs.**

BCE 2296 for further information

Electrically-operated Valves

A range of Vee-Reg electrically-operated valves, newly introduced, are actuated with Rotork units, which consist of totally-enclosed oil-filled worm and wheel reduction gearboxes with integral electric motor and electrical control boxes. The units are flanged, and ample room is provided for repacking the large

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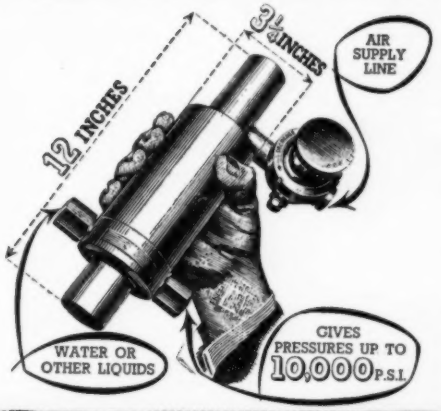

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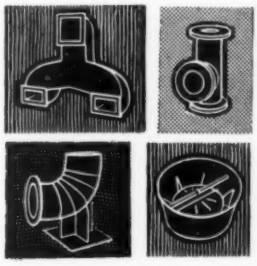

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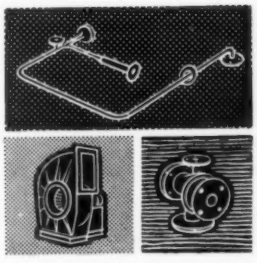

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BCE 2237 for further information

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stuffing boxes. A handwheel, which does not rotate during electrical operation, is fitted to each valve for use in the event of electrical power failure, or if hand operation is required. Heat-treated stainless-steel discs and seats of the company's design, having protected faces throughout the full movement of the valve, are built into the valves. The new products are available in the sizes 1½ to 10 in. with end flanges to B.S. tables E, F, H, or J and in sizes 2 to 4 in. with flanges to B.S. tables K or R. **British Steam Specialities Ltd., Fleet Street, Leicester.**

BCE 2297 for further information

Water Still

Apex Construction are introducing a range of water stills incorporating a glass condenser and having capacities of 3, 5 and 10 gallons an hour. The evaporator itself forms part of a standard

model HIOS. The still is a hard-water duty model fitted with a deconcentrator which continuously bleeds off impurities from the evaporator. The tinned-copper steam coil is mounted on a bolted removable plate for easy cleaning. A steam pressure of 25 to 55 psi is required and the still has an output of 10 gallons per hour at about 40 psi. **Apex Construction Ltd., 15 Soho Square, London, W.1.**

BCE 2298 for further information

Dust Collector

The new, No. 40, Guyson dust collector has been designed for treating dust-laden atmospheres at specified points in factories. It uses a compact form of fabric screen to secure a large area of filtration. Maintenance of the screen is simplified by a full-width door which, on being opened, automatically collapses the screens temporarily without switching off the fan motor. A hand-shaker mechanism releases the dust on the filter screens into a removable disposal drawer below. The motor is of ½ hp and the capacity of the collector is 350 cfm. The machine is of the dimensions 2 ft × 3 ft × 5 ft 6 in. **Guyson Industrial Equipment Ltd., North Avenue, Otley, Yorks.**

BCE 2299 for further information

Modified Cooling Tower

Head Wrightson have completed work on a new design of their Counterflo induced-draught cooling tower. The modifications include a new form of water distribution and of louvre intakes for air drawn in by an induction fan. The equipment is being made under licence by Fluor Products of Los Angeles. (A description of the counterflow type of cooling tower was contained in an article "Basic Principles of Cooling Tower Design", by D. J. Tow, of Head Wrightson, published in *British Chemical Engineering*, 1957, **2**, 263.) **Head Wrightson & Co. Ltd., 20 Buckingham Gate, London, S.W.1.**

BCE 2300 for further information

Other Items

Detel are manufacturing a new heat-resistant aluminium paint which, they say, will withstand temperatures of up to 600°C. They are also making a new epoxy resin paint, A.D. grade, which has been specially elaborated for the coating of centrifuge baskets and bowls. It will coat copper, mild steel or aluminium and is working successfully at temperatures of −15°C. **Detel Products Ltd., Victoria Park Estate, South Ruislip, Middx.**

BCE 2301 for further information

Rediweld have designed a plant in PVC for filtering electro-plating solutions. It comprises a submersible centrifugal PVC pump, which is portable and can be inserted into the plating bath. The filter is fitted with a bag made from Redivin PVC filter-cloth, and the bag is supported by a cylinder made from expanded polythene to prevent collapse during filtration. The pump's fixed discharge capacity is 350 gallons an hour. The company is also making available a series of plastic manometers. For carrying, the instruments may be rolled up. Water containing fluorescein and a wetting agent, or mercury, may be employed as the filling liquids. **Rediweld Ltd., 17-27 Kelvin Way, Crawley, Sussex.**

BCE 2302 for further information

A winch-operated hoist, said to be unique, has just been added to a new range of Lenson mobile step ladders. The smallest size has a platform height of 5 ft and its hoist is capable of lifting 120 lb. to a height of 7 ft. **Lenson Engineering Co., Churchill Road Extension, Thurmaston, Leicester.**

BCE 2303 for further information

Glen Creston's new disc mill, S.200, will cope, the makers say, with almost any substance. It can be operated by hand or by motor—when it has an output of up to 50 kilos an hour. **Glen Creston Ltd., Stanmore, Middx.**

BCE 2304 for further information

The manufacture of ventilated standard dimension motors type KN-C, built to B.S. draft specification CW (ELE) 6246 in a range of powers up to 40 hp at 1500 rev./min., has just been put on a full production basis by **The British Thomson-Houston Co. Ltd., Rugby.**

BCE 2305 for further information

The Airmec feeding hopper, type N235, will deliver small articles, at rates up to 6000 per minute, in single file and with sufficient space between articles to enable them to be counted electronically. **Airmec Ltd., High Wycombe, Bucks.**

BCE 2306 for further information

A compact, hydraulically operated work-bench which will lift loads of up to 500 lb. and is of wide application throughout industry has been developed by **Skyhi Ltd., Isleworth, Middx.**

BCE 2307 for further information

The Regeltron humidistat which incorporates an electronic relay, and having a humidity element actuated by synthetic hair, is being made available in Britain by **Alexander & Tatham Ltd., Victoria Chambers, South Parade, Leeds 1.**

BCE 2308 for further information

New Publications

A quick-acting balance recently designed by the Physics Department of B.I.S.R.A. is briefly described in the Association's Summary 114 just published. With such an instrument it should be possible to make about three times as many weighing operations per day as with a normal analytical balance, it is claimed. The balance beam is suspended at its centre of gravity so that no restoring force is applied if the beam is displaced. When a load is placed on one pan, the resulting movement of the beam is translated into an electric current, which is used to generate a restoring force in a coil and magnet system. The beam quickly takes up an equilibrium position in which these two forces are exactly balanced. The current which gives rise to the restoring force is directly proportional to the load, and can be indicated on a suitably calibrated meter. **The British Iron and Steel Research Association, 11 Park Lane, London, W.1.**

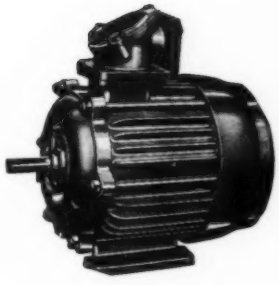
BCE 2309 for further information

NEW FILMS

Two new films in colour have just been released by Firth-Vickers' film unit. Both are intended for a user audience, are descriptive, and run for about thirty minutes. "The Manipulation of Corrosion- and Heat-resisting Steel", the fifth in the unit's series of productions, touches on many problems and processes involved in the fabrication of stainless-steel equipment. They include the preparation of sheets and plates for welding, cold bending of plates; metal arc welding; descaling and grinding to remove oxide; weld defects; oxy-acetylene, argon arc, resistance spot, seam and flash-butt welding; machining, pressing and polishing. Film No. 6, "Where Staybrite Steels are Made", takes the viewer on a tour of the departments of the company's Staybrite Works where the bars, sheets, strip and castings—the finished products of the company—are processed. Copies of the films are available on loan, free of charge, from **Firth-Vickers Stainless Steels Ltd., Staybrite Works, Sheffield, 9.**

BCE 2310 for further information

Delivery time of E·P·E Three Phase Flameproof motors now slashed by half!



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Month's News in Brief

In order to reflect the dual nature—oil and chemical—of operations at Shell's Pernis refinery, near Rotterdam, two separate operating companies are being formed. Shell Pernis Raffinaderij N.V. will concern itself with the manufacture of oil products and Shell Pernis Chemische Fabrieken N.V. with petroleum chemicals. The policies and working programmes of the two companies will be closely co-ordinated. This reorganisation will be implemented gradually and will be completed by the beginning of next year. It will not, say Shell, affect the manufacturing programmes or the execution of current contracts, nor will there be any change in the management at Pernis nor in the terms of employment of the staff.

A new company, Petrochem G.m.b.H., has been formed in Dortmund, Germany, by Birwelco Ltd. to manufacture Iso-Flow fluid heating furnaces to the design of Petro-Chem Development Co. Inc., of New York. The company has been formed to take its part in the tremendous expansion now being made in Germany's refining capacity, and will market, manufacture, erect and service Iso-Flow furnaces. The company has received its first order, which is from Esso A.G., of Hamburg, for its new refinery at Cologne. It is for seven furnaces for duties totalling 177.6 million Btu an hour, and including one of 85 million Btu an hour. The contract covers supply and erection, and is worth some £250,000. Birwelco's German company will be an entirely independent unit with German staff.

The supply of natural gas from the well at Cousland, Midlothian, was inaugurated by Sir Harold Smith, chairman of the Gas Council, on October 28. The gas will be mixed with the town's gas made at the Musselburgh gasworks, and distributed to Musselburgh, Cockenzie and Port Seton, Prestonpans and Tranent. The communities in these places will thus become the first in Britain to make commercial use of natural gas, and The Scottish Gas Board will be the first of the twelve Area Boards in Britain to benefit from the search for natural gas sponsored by the Gas Council, which has been carried out in conjunction with the B.P. Exploration Co. Ltd. in various parts of the United Kingdom.

The Department of Scientific and Industrial Research announce that the fuel research station at Greenwich is to be replaced by a new station at Stevenage (Herts.) estimated to cost about £750,000.

Partial occupation of the new 180,000 sq. ft factory of Permali Ltd. at Gloucester has now released more space in the existing works to expand the manufacture of P.T.F.E.

The Pulsometer Engineering Co. Ltd. have acquired the controlling interest in G. S. Tett & Co. Ltd., of Bedfont Lane, Feltham, Middlesex. Mr. F. B. Duncan (chairman) and Mr. J. S. Woodrow (managing director) of Pulsometer have joined the board of G. S. Tett.

The Second World Metallurgical Congress opened in Chicago on November 2.

A control installation for continuous diffusers at the British Sugar Corporation's factory at Wissington in Norfolk, and believed to be the first closed-loop electronic process control installation applied to the process of extracting sugar from sugar beet in the world, was designed by Evershed & Vignoles Ltd., in conjunction with the British Sugar Corporation.

A special inquiry is being held by the Federation of Engineering Design Consultants into wage rates and charges prevalent among its members. The purpose of the inquiry, which is anonymous, is to establish, *inter alia*, the relationship between wages and overheads and charges on an hourly basis to manufacturers. A report on the inquiry will be issued in due course.

The Council of Association between the Government of the United Kingdom and the High Authority of the European Coal and Steel Community have reached full agreement on proposals to be sent to the Governments of the six Community countries and the British Government for a substantial reduction of iron and steel tariffs in the United Kingdom and the Community.

A new fifteen-minute 16-mm film has just been completed which features the Atomat thickness gauge, manufactured by the Baldwin Instrument Co. Ltd., of Dartford, Kent.

The trading name of Horace Priest, Chemical Engineering Co. Ltd., Farthings Hill, Horsham, Sussex, has been changed to The Beverley Chemical Engineering Co. Ltd., Beverley House, London Road, Horsham. Tel.: Horsham 3211 and 3212.

Meetings of the Month

Institution of Chemical Engineers

November 19. *North-Western Branch:* At Reynolds Hall, College of Science and Technology, Manchester. Two Papers on Pressure Vessels, by R. W. Lakin and A. N. Other. **7 p.m.**

November 26 (whole day). *London Branch:* At The Royal Institution, 21 Albemarle Street, London, W.1. "Recent Developments in Industrial Low-temperature Gas Separation."

December 3. *North-western Branch:* At Birkenhead Technical College. "The Selection and Operation of Solvent Extraction Equipment", by J. A. H. Walker. **7 p.m.**

December 3. *London Branch:* At The Geological Society, Burlington House, London, W.1. "Shell Gasification Process and its Application to Industry", by M. J. Gattiker. **5.30 p.m.**

December 11. *Midlands Branch:* At the Midland Institute, Paradise Street, Birmingham. "Models for Piping Design and Construction", by M. K. Brown and E. Holmes. **6.30 p.m.**

December 17. *North-western Branch:* At Reynolds Hall, College of Science and Technology, Manchester. "Chemical Engineering Aspects of Gas-solid Reactions", by Prof. K. G. Denbigh. **7 p.m.**

Society of Chemical Industry

November 20. *Dublin and District Section:* At University College, Dublin. "Radioisotopes and Radiation Energy in Industry", by H. Seligman. **7.45 p.m.**

November 20. *Corrosion Group:* At 14 Belgrave Square, London, S.W.1. "Protection of Magnesium Alloys", by W. F. Higgins. **6.30 p.m.**

November 21. *Road and Building Materials Group:* At 14 Belgrave Square, London, S.W.1. "Producer - gas - fired Lime Kilns", by B. J. Gee. **6 p.m.**

November 22. *Aberdeen and North of Scotland Section:* At Physiology Lecture Room, Marischal College, Aberdeen. "High Conversion Polymerisation", by Prof. G. M. Burnett. **7.30 p.m.**

November 22. *South Wales Section:* At Cardiff University College. "The Preparation and Reactions of Nylons", by A. R. Munden. **7 p.m.**

December 2. *London Section:* At 14 Belgrave Square, London, S.W.1. "High-pressure Reactions", by Prof. D. M. Newitt. **6.30 p.m.**

December 3. *Birmingham and Midland Section:* At Cinema, Birmingham and Midland Institute, Paradise Street, Birmingham, 1. "Nuclear Magnetic Resonance", by Dr. R. E. Richards. **6.30 p.m.**

December 5. *Glasgow Section:* At Central Hotel, Glasgow. "The Ramsay Dinner". **6.30 p.m. for 7 p.m.**

December 5. *Bristol Section:* At University Chemical Department, Woodland Road, Bristol, 8. "Design and Operation of Waste-heat Boilers in the Chemical Industry", by W. Gregson. **6.30 p.m.**

December 5. *Nottingham Section:* At Lecture Theatre, Nottingham and District Technical College. "Automatic Control in Fine Chemical Manufacture", by A. H. Isaac. **7.30 p.m.**

December 5. *Pesticides Group:* At Physiology Lecture Room, Marischal College, Aberdeen. "Pesticides—Problems and Prospects", by Dr. R. A. E. Galley. **7.45 p.m.**

December 6. *Glasgow Section:* At Royal College of Science and Technology, Glasgow. "William Ramsay—a Glasgow Man", by A. Kent. **7.15 p.m.**

December 6. *Fine Chemicals Group:* At 14 Belgrave Square, London, S.W.1. "Problems in Supplying Laboratory Chemicals", by K. G. A. Hammer. **6.30 p.m.**

December 10. *Chemical Engineering Group:* At 14 Belgrave Square, London, S.W.1. "Continuous Processing in the Oil and Fats Industry", by Dr. B. Brae. **5.30 p.m.**

December 12. *Liverpool Section:* At Liverpool Engineering Society Rooms, The Temple, Dale Street, Liverpool. "Titanium", by J. W. Rodgers. **7 p.m.**

December 18. *Corrosion Group:* At 14 Belgrave Square, London, S.W.1. "Teaching Corrosion Science"; "Existing Facilities", by L. W. Stubbs, and "Future Requirements", by T. P. Hoar. **2.30 p.m.**

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The Physical Society

November 26. *Low Temperature Group:* At the Royal Institution. "Recent Developments in Industrial Gas Separation".

December 19. At Imperial College, London. Two-day Conference on Band Theory of Metals and Experimental Investigations into the Structure of the Fermi Surface. Until **December 20.**

The Institute of Fuel

November 27. At the Institution of Civil Engineers, Great George Street, Westminster, S.W.1. The Second Conference on "Pulverised Fuel". Until **November 28. 10 a.m. both days.**

The Institute of Metals

November 20. *Manchester Metallurgical Society:* At Manchester Room of the Central Library, Manchester. "Metallurgical Education", by Prof. G. W. Raynor. **6.30 p.m.**

December 4. *Powder Metallurgy Joint Group:* At Church House, Great Smith Street, London, S.W.1. "Recent Developments in Powder Metallurgy", by Ivor Jenkins; "Developments in the Production and Quality of Metal Powders". Presentation of short papers followed by discussion. **10.30 a.m.**

December 4. *Manchester Metallurgical Society:* At the Manchester Room of the Central Library, Manchester. "The Metallurgical Applications of High Resolution Electron Microscopy", by J. Nutting. **6.30** p.m.

December 5. *Joint Meeting with the Chemical Engineering Group of the Society of Chemical Industry:* At the Chemical Department, The University, Woodland Road, Bristol. "Design and Operation of Waste-heat Boilers in the Chemical Industry", by Captain W. Gregson. **6.30 p.m.**

December 5. *Leeds Metallurgical Society:* At Lecture Room C, Chemistry Wing, The University, Leeds, 2. "Some Uncommon Failures of Engineering Plant in Service", by G. A. Cottell. **7.15 p.m.**

December 9. At the Atomic Energy Research Establishment, Harwell. Symposium on "Vacancies and other Point Defects in Metals and Alloys". Until **December 10.**

December 9. *Scottish Local Section:* At Institution of Engineers and Shipbuilders in Scotland, 39 Elmbank Crescent, Glasgow, C.2. "Recent Developments in Magnesium-base Alloys", by E. F. Emley. **6.30 p.m.**

December 10. *South Wales Local Section:* At Department of Metallurgy, University College, Singleton Park, Swansea. "Hardness of Metals", by D. Tabor. **6.30 p.m.**

December 11. *North-east Metallurgical Society:* At the Cleveland Scientific and Technical Institution, Corporation Road, Middlesbrough. "Stress-corrosion Cracking", by T. P. Hoar. **7.15 p.m.**

December 11. *London Local Section:* At Constitutional Club, Northumberland Avenue, London, W.C.2. "Properties of Castings", by F. Hudson. **7.30 p.m.**

Society of Glass Technology

November 27. At the Lecture Theatre, "Elmfield", Northumberland Road, Sheffield, 10. "Symposium on Radioisotopes and Glass." **9.30 a.m. to 4.15 p.m.**

December 13. *North-west Section:* At The Gamble Institute, Victoria Square, St. Helens. "The European Free Trade Area and How it may Affect the British Industry", by D. Rider. **6.15 p.m.**

Scientific Film Association

November 21. At the Mezzanine Cinema, Shell Mex House, Strand, London, W.C.2. "Documentary and Scientific Films in the U.S.S.R.—Some Impressions", by D. Alexander, Films Officer, National Coal Board. **6.30 p.m.**

People in the News

Sir Harold Smith, chairman of the Gas Council, was installed on October 3 as the first honorary president of the newly-formed Houldsworth Society at Leeds University. The Society commemorates the late Sir Hubert Houldsworth, chairman of the National Coal Board until his death in February, 1956, who was a student and member of the staff of the Coal, Gas and Fuel Department of Leeds University and pro-chancellor for six years. In recent years the department of Coal, Gas and Fuel has expanded and outgrown its title. Two new departments, Chemical Engineering and Metallurgy, have been opened and the parent department renamed the Department of Gas Engineering, General Fuel Science and Ceramics. These three departments now form the Houldsworth School of Applied Science, whose 200 students will move into their new £610,000 building in May next year. All the students are members of the Society which acts as a forum for discussion. Sir Harold will preside at all major functions during his year of office.

Mr. A. S. C. Hulton, managing director of Shell Tankers Ltd., was appointed a director of the Shell Petroleum Co. on October 9, 1957.

Mr. R. A. Eede has joined the staff of Alite Machines Ltd.

Mr. A. R. G. Williams has been appointed managing director of National Adhesives Ltd. Mr. Williams joined National when they commenced operations in England in 1928, and was appointed sales manager in 1931, joining the board as sales director two years later.

At a recent meeting of the board of the Dunlop Rubber Co. Ltd., it was announced that **Sir George Beharrell** had resigned from the presidency of the company and therefore from the board, but had consented to act as an honorary consultant. **Lord Baillieu** expressed the wish to be relieved from his duties as chairman of the company. The board acceded to Lord Baillieu's request, but welcomed his willingness not only to remain on the board but also to succeed Sir George Beharrell as president of the company. Mr. G. E. Beharrell was elected chairman of the board in succession to Lord Baillieu and will continue to act as chief executive of the company. **Mr. John H. Lord** was appointed a managing director. He expressed his desire to retire from executive work about the end of 1958, but agreed that afterwards he would serve as a non-executive member of the board.

Mr. R. M. Geddes was appointed a managing director, and **Mr. T. E. Peppercorn** was appointed an executive member of the board.

Chemical Construction (Great Britain) Ltd. announces that **Mr. James Curtis**, formerly executive vice-president of the Lummus Co., became, as from August 15, president of its affiliated company in New York, the Chemical Construction Corporation.

Mr. E. L. Burton has been appointed secretary of Tube Investments Ltd. in succession to **Mr. I. N. Turner**, who has taken up other duties in the group.

Chemstrand Ltd. have announced the appointment of **Mr. Cole Downing** as technical manager for their Acrilan plant, now in course of construction at Coleraine, Northern Ireland. The plant, which will have an initial capacity of 10 million lb. of acrylic fibre a year, will be in full production by the end of 1958.

The council of the British Iron and Steel Federation has appointed **Mr. Lewis Chapman** (chairman, William Jessop & Sons Ltd.) president-elect of the Federation in succession to the late **Mr. Gerald Steel. Sir Andrew McCance** (chairman and managing director, Colvilles Ltd.) has been invited to continue in office as president of the Federation for 1958.

A. S. C. Hulton.

A. R. G. Williams.

Sir George Beharrell.

Lord Baillieu.

Mr. James Curtis.

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